HYDROGEN ENERGY

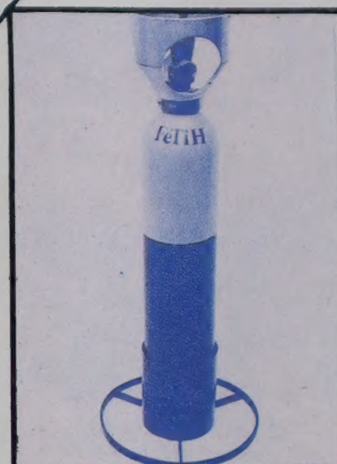
EXPERT GROUP MEETING AT KATHMANDU, NEPAL, 1992

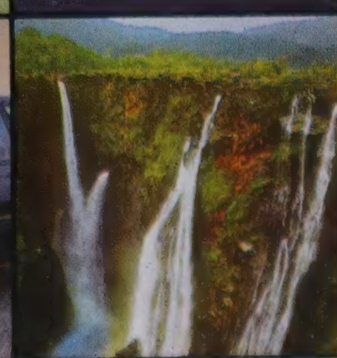
$$2H_2O \rightleftharpoons 2H_2 + O_2$$

H_2 GAS

HYDRIDES

LIQUID-H_2





ASIAN AND PACIFIC CENTRE FOR TRANSFER OF TECHNOLOGY

New Delhi, INDIA

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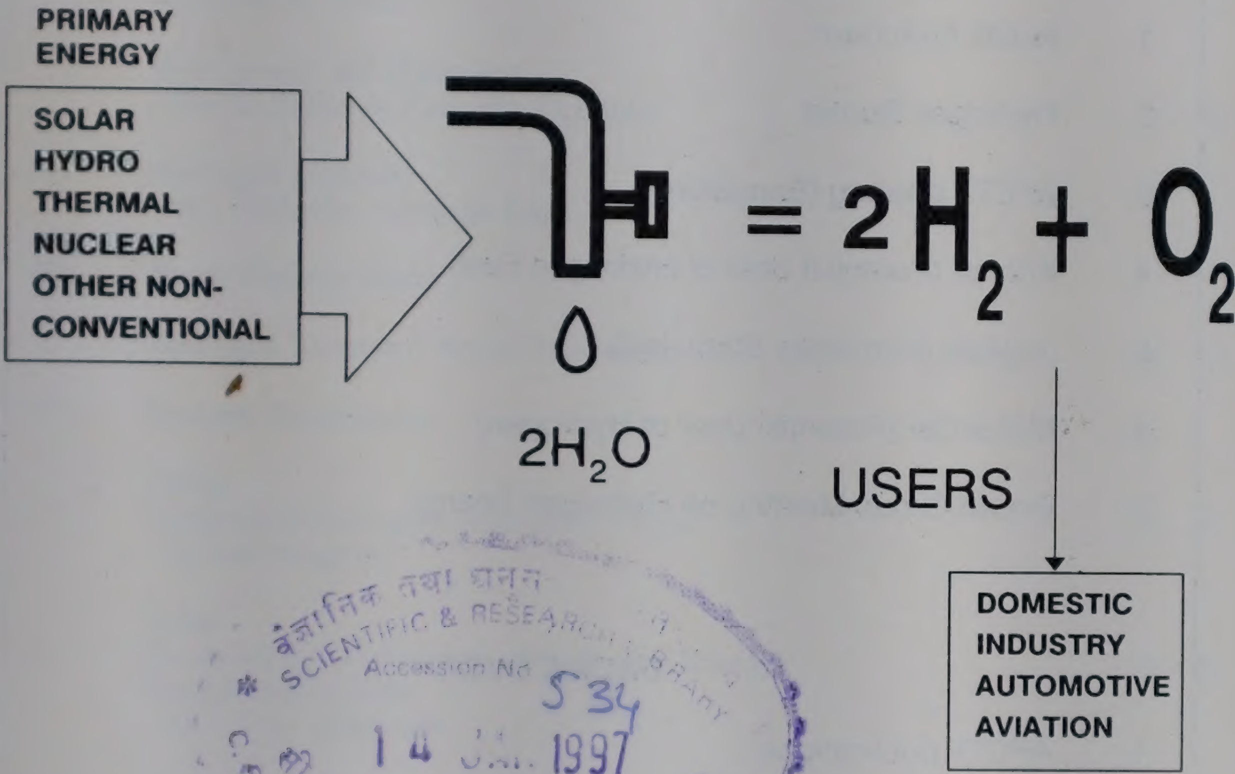

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New Delhi, INDIA

September 1993

The Legend of the cover page as well as back page

FRONT COVER

1. Idukki Arch Dam
2. Hydrogen Burner
3. APCTT building (Bangalore)
4. Aircraft (Potential User of Hydrogen Fuel)
5. Jogfalls (Karnataka State, India)
6. Motor Car (Potential User of Hydrogen)
7. Expert Group Meeting on Hydrogen Energy

BACK COVER

1. APCTT publications
2. Periodicals on display in APCTT Library
3. Inside view of the APCTT Library
4. Another view of APCTT Library
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PREFACE

The Asian and Pacific Centre for Transfer of Technology (APCTT) was established by the United Nations Economic and Social Commission for Asia and Pacific (UN ESCAP) in 1977. Recently relocated to New Delhi from Bangalore, India, APCTT acts as a base for ESCAP's technology transfer activities for all of Asia and the Pacific. We are proud to bring out this publication from the Centre's new premises in New Delhi.

The statute of APCTT was adopted by ESCAP at its 41st Commission Session held in April 1985. The Centre receives its overall policy directives from the annual ESCAP sessions and specific guidelines from the annual session of its Governing Board. The objectives of the Centre are 1) to assist the members of ESCAP by strengthening their capacity to develop, transfer, adopt technology; and 2) to identify and promote the development and transfer of technologies relevant to the region. Recognizing the importance of balance between economic development and ecological management, the Centre has placed a special emphasis on promotion of environmentally friendly technologies.

The publication is a compilation of selected papers and a consultant's report presented at the "**Joint UNIDO/APCTT Expert Group Meeting on Hydrogen as an Energy Alternative for Developing Countries**" which was held in Kathmandu from 6 to 10th July, 1992. The Royal Nepal Academy of Science and Technology (RONAST), Kathmandu provided the required host facilities for the meeting. It was attended by 11 country participants, 6 international experts, 4 consultants, 2 ESCAP officials, 2 UNIDO officials and 2 APCTT officials. At the Expert Group Meeting, every one of the participants contributed valuable comments and suggestions at the meeting and thanks are due for their participation in the Meeting.

Prior to the Meeting, a team of consultants in Nepal headed by Mr. Khilendra N. Rana and Mr. Dwarika Man Shrestha was entrusted to prepare necessary background material. They produced the document, "Hydrogen Study: Nepal,". Due to its length, it could not be reproduced here in its entirety, but the most significant parts of it was split into three sections and reproduced in: Chapter II, III, and Appendix. It is an excellent assessment of hydrogen's potential in Nepal, and the whole study is available at the Centre.

The Centre is grateful for the generous contribution of GTZ and the Government of Australia who sponsored many of the participants. UNIDO's contribution, support and assistance in organization and implementation of the project is deeply appreciated and the Centre looks forward to further cooperation with UNIDO in future.

The Centre acknowledges the lead role of Mr. Ove Chr. Bugge, the former Director of APCTT for his interest in the subject and his contribution at the meeting and the supportive role of Ms. Jaana Pelkonen, a former Associate Expert, who coordinated the meeting. Special mention should be made of the efforts of our staff, Ms. Aya Konishi, Associate Expert, and Ms. Annette Joseph, in compilation of this document.

September 1993
New Delhi, India

Dr. K.V. Swaminathan
Acting Director

ABBREVIATIONS

H_2	-	Hydrogen
O_2	-	Oxygen
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
GH_2	-	Gaseous hydrogen
LH_2	-	Liquid hydrogen
MH_2	-	Metallic hydride
NO_x	-	Nitrogen oxides
I.C. Engine	-	Internal Combustion Engine
S.I. Engine	-	Spark compression-ignition engine
C.I. Engine	-	Compressed-ignitio engine
D.I.	-	Direct injection
LHV	-	Lower heating value
HHV	-	Higher heating value
J	-	Joule
GJ	-	Gigajoule (10^9 joule)
Kcal	-	Kilocalorie
KJ/kg	-	Kilojoule per kilogramme
KJ/m^3	-	Kilojoule per cubic meter
MJ	-	Megajoule (10^6 joule)
Nm^3	-	Normal meter cubic
SCF	-	Standard cubic feet
g/cm^3	-	Gramme per cubic centimeter
Cm	-	Centimeter
m	-	Meter
in	-	Inch
m/sec	-	Meter per second
cm/sec	-	Centimeter per second
in/sec	-	Inch per second
Lt	-	Litre
kl	-	kilolitre
Mt	-	Metric tonne
Rs/lt	-	Nepalese rupees per litre
Rs/kl	-	Nepalese rupees per kilolitre
$/GJ	-	U.S. Dollar per gigajoule
Rs/Mt	-	Nepalese rupees per' metric tonne
Vol %	-	Volume percentage
°C	-	Centigrade
°F	-	Fahrenheit
°K	-	Kelvin
atm	-	Atmosphere
psi	-	Pressure per square inch
Kw	-	Kilowatt
Mw	-	Megawatt
Kwh	-	Kilowatt-hour
Mwh	-	Megawatt
Gwh	-	Gigawatt-hour
KVA	-	Kilovolt-ampere
Kwh/Nm^3	-	Kilowatt-hour per normal cubic meter

CIF	-	Cost, insurance and freight
M	-	Million
HSD	-	High-speed diesel oil
ATF	-	Aviation turbo fuel
LPG	-	Liquid petroleum gas
PV	-	Photo voltaic
NOC	-	Nepal Oil Corporation
WECS	-	Water and Energy Commission
TCN	-	Timber Corporation of Nepal
INPS	-	Integrated Nepal Power System

AUTHORS

1. **Implementation of a Standardized World Hydrogen System**
   - Gustov R. Grob, President CMDC/ICEC & Chairman ISO/TC, Zurich, Switzerland

2. **Hydropower and Hydrogen**
   - Koichi Fujino & Kazuhiko Ogimoto, International Workshop Seminar on Energy and Sustainable Development in a World Context, May 1992, Electric Power Development Co., Ltd

3. **Hydrogen Economy**
   - Khilendra Narsingh Rana, Institute for Sustainable Development, P.O. Box 4006, Lalitpur, Kathmandu

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   - Khilendra Narsingh Rana, Institute for Sustainable Development, P.O. Box 4006, Lalitpur, Kathmandu

5. **Electrolytic Hydrogen Potential in China**
   - Liu Hongyun, Sr. Eng., Vice Director, Hunan Hydro & Power Department, China

6. **Prospects and Perspective of Hydrogen Programme in India**
   - O.N. Srivastava, Area Co-ordinator on Hydrogen Energy Programme, Department of Physics, Banaras Hindu University, Varanasi 221 005

7. **The Prospect of Hydrogen Energy Development in Indonesia**
   - Nenny Sri Utami, Directorate General of Electricity and New Energy, Ministry of Mines & Energy

8. **Hydrogen: Future Technology for Malaysia**
   - Prof. Madya Dr. Abdul Halim Shamsuddin, Head of Dept, Dept. of Mechanical Engineering, Universiti Kebangsaan Malaysia, 43000 Bangi, Malaysia

9. **Prospects of Hydrogen Technology**
   - S.N. Sarwar, Manager, Hydrocarbon Development Institute of Pakistan

10. **Use of Hydrogen Fuels in the Philippines**
    - Marites I Cabrera, Officer-in-Charge, Non-Conventional Resources Division, Office of Energy Affairs, Republic of Philippines

Appendix A: Hydrogen Scenario in Nepal

- Khilendra Narsingh Rana, Institute for Sustainable Development, P.O. Box 4006, Lalitpur, Kathmandu

I. INTRODUCTION

EXECUTIVE SUMMARY

Expert Group Meeting on Hydrogen as an Energy Alternative for Developing Countries 6 - 10 July , Kathmandu, Nepal

1. Introduction

The Expert Group Meeting on Hydrogen as an Energy Alternative for Developing Countries organized by the Asian and Pacific Centre for Transfer of Technology (APCTT) and United Nations Industrial Development Organization (UNIDO) in cooperation with the Royal Nepal Academy of Science and Technology (RONAST) was held in Kathmandu, Nepal from 6 to 10 July 1992. The Expert Group Meeting was attended by 8 country participants from the developing countries of the region and 13 international experts from industrialized countries and from UN organizations. There were also representatives from the host organization RONAST, local consultants and observers from Nepalese energy organizations, total participants number raising to 28. A list of participants is attached in Appendix 2.

The objective of the Expert Group Meeting was to exchange views and create awareness on the potential of hydrogen as an energy alternative and to explore the possibility for developing countries to acquire capability to transfer and adapt the technology to their specific needs. The meeting discussed prior experience, current policy, recent technology developments and prospects for hydrogen as energy.

Particularly it focused on the following topics :

- utilization of surplus hydraulic/electric energy at hydropower sites
- hydrogen generation through electrolysis of water
- collection, transport and storage of hydrogen for fuel use
- conversion of internal combustion engines and vehicles to hydrogen fuel
- conversion of small scale domestic appliances to hydrogen fuel
- economic attractiveness of hydrogen fuel and social/cultural issues

The output of the meeting is a compendium of 15 technical papers, which addressed issues like

- current sources of information on hydrogen energy
- identification of organization and institutions willing and able to act as international centres for the collection and dissemination of data in specific technological/economic areas
- elaboration of project concepts, which promote R&D of hydrogen energy in the developing countries, to be submitted for funding to donor organizations.
- identification of organizations and institutions willing and able to provide funds for R&D in hydrogen energy in developing countries.

2. Opening of the meeting

The meeting was officially inaugurated by the Minister of State for Water Resources of Nepal, the Hon. Laxman Prasad Ghimire. The other opening statements were delivered by Mr. Ove Chr. Bugge, Director of APCTT, Mr. George Tabah, Industrial Development Officer from UNIDO, Prof. Parasar N. Suwal, Chairman of RONAST and Mr. Rishi Shah, member of RONAST.

Mr. Ove Chr. Bugge APCTT stated that this is the first meeting focusing the potential of hydrogen for developing countries. The ultimate objective is to find out how to apply available technology in this region and to create an experimental hydrogen community. He said that the meeting could be ground-breaking and UN will consider the long time advantages of hydrogen energy in its development programmes.

Mr. George Tabah, UNIDO mentioned that UNIDO has been for several years active in developing renewable energy technologies especially solar energy and only a few years ago it became interested in hydrogen, especially produced from renewable energy. UNIDO is happy to sponsor meetings involving experts and energy leaders of countries and initiate pilot operations for hydrogen which is the role of this meeting. He also brought message from the 9th World Hydrogen Energy Conference which was held in Paris two weeks earlier and where the general consensus was that hydrogen will replace fossil fuel as the energy carrier of the future. He hoped that this meeting in Kathmandu may show that the future is now.

Minister of State for Water Resources of Nepal, the Hon. Laxman Prasad Ghimire, spoke of Nepal government's support and said that Nepal is very pleased to implement pilot projects on hydrogen. According to him hydrogen produced from electrical energy from run-of-the-river hydro plants has many benefits. The hydrogen can be used for transportation and other applications and can help reduce deforestation by meeting domestic heating and cooking needs. Due to Nepal's increasing hydro-energy production there will be surplus hydro power in the future. Use of this surplus to produce hydrogen, with adequate storage, and appropriate end uses to meet specific needs can help Nepal develop which makes use of surplus hydro as a key potential area in Nepal's future.

Prof. Parasar N Suwal, Chairman, RONAST gave the keynote address in which he stressed the need to address energy alternatives. He said there is need for donor assistance and programs that will benefit the countries like the proposed hydrogen program. Nepal's water source is abundant as the supply for both power and electrolysis. He congratulated the authors of the report prepared on Nepal and agreed with them the problems of financial requirements and dependence upon foreign sources of capital is critical. There is the danger of reliance on more and more foreign imports of fossil fuel in the future and only increased support directly to science and technology can make the country more self-reliant. He said Nepal is willing to take a lead in the development, monitoring and reality of this program.

Mr. Rishi Shah, Member of RONAST expressed thanks to all of the participants for coming to Nepal from their home countries and thanked UN for making it possible for RONAST to host this meeting. He added that making hydrogen relevant for Nepal gives to the country great hope and RONAST will do what them can to make this program a reality.

Ms. Jaana Pelkonen from APCTT informed the meeting on the role of UN/APCTT in promoting new hydrogen technologies to the developing countries. She also pointed out the importance of the technology transfer process in developing new energy alternatives and summarized the purpose of meeting as developing proposals for submitting to donor agencies and identifying possible agencies for sources of funds.

Mr. George Tabah reported on UNIDO interests in Hydrogen and on the International Center for Hydrogen Technology. The profile of the centre would be the coordination, collection of information and resources and promoting research and development of specific areas of specific interest by developing countries. UNIDO has allocated the funds for the feasibility study of the center and the Government of Turkey has made an offer to sponsor the center and pay for the local costs.

The keynote presentation was by N. Veziroglu, College of Engineering, University of Miami, USA. He is a long time supporter and thorough on hydrogen technology and informed that energy global demand is increasing at 1.8% per year only half of the population growth rate. Energy demand is directly proportional to standards of living. If a country consumes more energy, it has a higher standard of living. Today, 80% energy comes from fossil fuel. Consumption of natural gas will continue to rise until 2010, coal as solid fuel will decline. He thereafter emphasized and explained the environmental aspect of hydrocarbon fuels.

Problem of smoke, acid rain, hydrocarbons, carbon dioxide, carcinogenians, oxides of nitrogen/sulphur, carbon monoxide, etc. are all due to pollution from hydrocarbons. He underlined that the real cost to the society from this use of hydrocarbons is far more than the production price, actually 2-3 times more.

The total damage to society from use of hydrocarbons was calculated to be the astronomical figure of US$ 2,260,000,000, 15% of the world GNP.

Hydrogen energy, as compared to gasoline is lighter (but occupies more space), safer, abundant (in water) transportable, clean, flexible, storable and has a high efficiency. The technology is available.

Hydrogen energy has therefore all properties to become the global fuel of the future.

There were country presentations by Malaysia, Philippines, India, Pakistan, Indonesia and China as well as presentations by others.

Finally the meeting agreed to the following statement :

1. The participants stated that similarly hydrogen fuel could be beneficial to other countries in controlling emissions, providing necessary economic growth and taking care of depletion of fossil fuels.

2. The participants noted with interest that hydrogen technologies in several fields have reached the stage of maturity, allowing hydrogen to be used for practical applications as the cleanest and most sustainable fuel.

3. The participants recognised use of hydrogen as a potential energy storage medium for resources such as run-of-the-river type hydro electricity.

4. The participants agreed with the conclusions of the study made by APCTT and other studies that based on total societal energy calculations, hydrogen produced from solar, hydro or wind power is the most economic fuel of all alternatives.

5. The participants recommend to start as soon as possible a pilot and demonstration programme for hydrogen energy in Nepal in cooperation with Asian and overseas experts, industries and organizations and to develop similar plans in other countries of the Asia-Pacific region.

6. The participants recommend to all interested parties at United Nations, Government and non-government levels to support the hydrogen pilot and demonstration programme in Nepal and in other Asian countries.

7. It is further recommended that the implementation of hydrowind and solar power projects should be accelerated in the region aimed at full clean and renewable energy self-sufficiency. Some countries may even become a clean energy exporters at a later stage.

8. The participants further recommend the countries of the region get involved in the work of the relevant committees of ISO and other international fora.

II. GLOBAL PERSPECTIVE

IMPLEMENTATION OF A STANDARDIZED WORLD HYDROGEN SYSTEM

Gustov R. Grob

Abstract

This introduction into the international standardization of hydrogen technologies by technical committee TC 197 of the International Standards Organization ISO on Hydrogen Energy will help everybody involved in hydrogen equipment manufacture, trading, R&D, design and testing to understand the reasons why ISO-standards are indispensable for the production, custody transfer and application of hydrogen as an energy commodity.

1. Introduction

The development of the hydrogen energy technology has now reached a stage that gives reason for hope to see commercially available production, storage and transport systems as well as practical calorific and automotive applications in service in the near future.

To facilitate the implementation of internationally operable hydrogen distribution chains, storage infrastructures and fuelling systems, the standardization of interfaces, safety requirements, product specifications, test procedures and measurement systems have to be created urgently to permit the international exchange of products.

This paper describes the new Technical Committee 197 of the International Standards Organisation ISO in Geneva, with its liaisons to relevant bodies and how the technical subcommittees and groups of experts are structured and organized. Its impact on the accelerated introduction programme of hydrogen energy into the clean energy age will be discussed.

2. The basic need for International Standards

International standards are needed for product classifications and specifications, systems, subsystems, components and methods, if they are internationally traded and publicly used. Such norms are imperative when interfaces, compatibilities, product interchangeability, performance standards, custody transfers or public safety are at stake.

The world economy would collapse, if there would be no international standards for measurement units, methods and instruments, nuts and bolts, tires, plugs, fittings and flanges, letter-film and credit card sizes, fuel qualities, modular transport, software codes and computer compatibilities. Without standardized technologies and transmission codes clear communication would be impossible. Without product quality specifications and standardized test methods intolerable safety risks would have to be taken and multinational enterprise would be hampered by technical trade barriers and litigation.

From past experience it was costing huge amounts of money to undo discrepancies between national or company standards. This can be avoided by the timely coordination between industries developing new generations of products.

Hydrogen energy is a perfect example, where international standards are indispensable and have to created simultaneously with the industrial development and in advance of market introduction; this in order to avoid belated harmonization of interfaces and expensive readaptation.

Neither hydrogen cars nor hydrogen fuel pumps could be built without standard fuelling interfaces, nor could the safety, quality and quantity of hydrogen and oxygen as energy carriers be assured and measures without international standards.

The development of the hydrogen technology has now reached a stage that gives reason for hope that this cleanest fuel of all fuels will soon be able to substitute the dwindling and lethal fossil energies. Industry and governments must act fast to save our environment and climate from a pollution holocaust.

Therefore hydrogen energy technology standards must be created urgently for:

- hydrogen fuel and oxygen byproducts terminology
- hydrogen and oxygen product classification and specifications
- automotive, aeronautic and calorific fuelling and systems interfaces
- stationary and mobile H_2 and O_2-handling, storage and liquefaction systems
- H_2 + O_2 production by solar-thermal, photovoltaic and photochemical methods
- static and dynamic measurement, instrument calibration and proving methods
- transportation by pipelines, ships and land vehicles
- fittings, flanges, gaskets and venting devices
- quality test methods and procedures
- safety standards and procedures

ISO Technical Committee TC 197 is handling these subjects expediently in subcommittees (SCs) and working groups (WGs) with the support of experts from industry, institutes and governments from all over the world, according to a list of priorities and in liaison with relevant organizations. SNV, Switzerland is providing the secretariat and chairmanship for this New Technical Committee.

Nearly, 100 nations are members of ISO through their national standards associations like DIN, ANSI, AFNOR, SNV. 20,000 experts are working in several hundred technical committees, subcommittees and in over one thousand working groups to create new standards in all fields of industrial activity. Our 400 international organizations maintain liaison with ISO, such as IEC, UN, OIML, ILO, WHO, WMO, CMDC/World Energy Coalition. ISO headquarters are located in Geneva adjacent to IEC, the International Electrochemical Commission.

Enclosed <u>Strategic Policy Statement, Committee Structure and ISO-Liaisons for TC 197</u> illustrate the need, urgency, justification and structure of this new technical committee, counting some two dozen member nations from East and West.

ISO/TC 197 HYDROGEN ENERGY STRATEGIC POLICY STATEMENT

Need for International Standards

To facilitate the economic and safe production, storage, transport and utilization of hydrogen as an environmentally compatible energy carrier and feedstock, international standards are needed.

Urgency

Bioenvironmental constraints and climatic change, due to the exponential growth of pollution form fossil resources, call for the urgent production of hydrogen as a clean, renewable type of energy.

Justification

Hydrogen, produced from water and recombined with oxygen back to water, is the favourite clean fuel, energy carrier and energy stock. Without international standards the common use and custody transfer of hydrogen would be jeopardized. GATT and EC-regulations require the free trade of nay commodities without the hindrance of technical barriers.

ISO/TC 197 Hydrogen Energy

LIAISONS

ISO/TC 5	Ferrous Metal Pipes
ISO/TC 8	Shipbuilding and Marine Structures (Gas Ships)
ISO/TC11	Boilers and Pressure Vessels
ISO/TC 20	Aircraft and Space Vehicles
ISO/TC 22	Road Vehicles
ISO/TC 23	Tractors and Machinery for Agriculture and Forestry
ISO/TC 28	Petroleum Products and Lubricants (Tank Calibration and Automatic Tank Gauging)
ISO/TC 30	Measurement of Fluid Flow in Closed Conduits
ISO/TC 37	Terminology (Principles and Coordination)
ISO/TC 47	Chemistry (Hydrogen as a Product and Feedstock)
ISO/TC 58	Gas Cylinders
ISO/TC 70	Internal Combustion Engines (Hydrogen Engines)
ISO/TC 86	Refrigeration (Cryogenics)
ISO/TC 94	Personal Safety - Protective Clothing and Equipment
ISO/TC 104	Freight Containers (Tank Containers)
ISO/TC 110	Industrial Trucks (With Hydrogen Engines)
ISO/TC 115	Pumps
ISO/TC 116	Space Heating Appliances (with Hydrogen Fuel)
ISO/TC 118	Compressors
ISO/TC 138	Plastic pipes, fittings and valves for fluids
ISO/TC 153	Valves
ISO/TC 158	Analysis of Gases
ISO/TC 161	Control and Safety Devices for Non-Industrial Gas-Fired Appliances and Systems
ISO/TC 163	Thermal Insulation (for Refrigerated Hydrogen)
ISO/TC 180	Solar Energy (for the production of solar hydrogen)
ISO/TC 185	Safety Devices/Protection against Excessive Pressure
ISO/TC 192	Gas Turbines
ISO/TC 193	Natural Gas (mixing and measurement aspects)
IEC	Electrical Aspects of Hydrogen Production and Use
OIML	Legal Metrology/Static and Dynamic Measurement

ISO/TC 197 HYDROGEN ENERGY TECHNOLOGY

Technical committee for the standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen as energy carrier.

SC 1 **Terms, definitions and related documentation**

Glossary of terms with definitions to be used in hydrogen energy technologies; classification and product specification of hydrogen and hydrogen mixtures

SC 2 **Quality and Quantity Determination**

Standardization of (a) methods and devices for the analysis and testing of; (b) measurement and quantity calculation methods and devices for hydrogen in gaseous, liquid, bonded and/or absorbed state

SC 3 **Storage, Transport and Handling of Hydrogen**

Design, construction, operation and maintenance of hydrogen energy storage, transport and handling systems

SC 4 **Safety**

Safety measures and guidelines for the safe production, storage, transport, handling and applications of hydrogen

SC 5 **Surface Vehicles**

Engines, fuel supply and control systems, on-board fuel storage systems, refuelling systems, and safety devices used for hydrogen fuelled surface vehicles.

SC 6 **Aerospace Systems**

On-board, ground-based and space-based hydrogen systems and subsystems used in support of hydrogen-propelled aeronautical and space/vehicles/machines

SC 7 **Electrochemical Devices**

Electrolyzers, fuel cells and other electrochemical systems and devices

SC 8 **Hydrides**

Hydriding materials (metals and/or alloys) and applications of hydriding materials - hydrogen systems such as for heat pumps, heating, cooling, pumping, compressing, purifying and electricity production.

SC 9 **Environment**

Environmental protection guidelines for the design, construction, operation and decommissioning of hydrogen energy related systems and devices, and disposal of related wastes

SC 10 **Industrial and Domestic Combustion Applications**

Stationary hydrogen energy applications, such as electrical power generation, cooking, space process heating and cooling.

HYDROPOWER AND HYDROGEN

Koichi Fujino & Kazuhiko Ogimoto

1. Introduction

"Sustainable Development", aiming at coexistence of economic development and environmental preservation to meet the present needs without harming the ability of future generations, is the dominant phrase for the global environmental issues. The hydroelectric power is ready to play an important role as the representative of natural or renewable energy in achieving the sustainable development under the restraints of both resources and environment.

The advantages of hydropower for the sustainable development are: renewable energy to be a stable energy supplier as well as a conservative of finite fossil fuels, clean energy source to be carbon-free and contributing to the environmental preservation, and realistic technology established in long history and applicable freely to the required scale of development.

Even though the hydropower is remarkably superior to other sources of energy, it is useless if there is not enough interest in developed countries such as U.S., Europe and Japan. The exploitable hydro potential, however, is reported to be as large as world annual electricity generation. The potential value of hydro-energy is different depending on the report and date because the data has been prepared based on investigation and economic evaluation particular to respective countries. That is also the reason of necessity for global investigation of hydropower resources.

Following three items are essential for the promotion of hydropower development: 1) basic investigations on a global scale including the assessment of environmental problems 2) research and development of the surrounding technology including the energy transportation with the aid of hydrogen 3) finance and organizations for all phases of hydropower development.

This paper treats briefly the advantages and potential of hydropower, introducing the net energy ratio and unit CO_2 emission, worldwide basic investigation, the global clean energy network system including energy transportation with hydrogen, and proposal of international cooperation for the development of hydropower potentials.

2. Advantages and Potential of Hydropower

Table 1 shows the net energy ratio between output and input energy throughout the life of several kind of power plants as well as the unit CO_2 emission.

Input energy contains the energy for construction of power plant and for its operation and maintenance including fossil fuels. The energy during construction has been accumulated with assorted materials required for the typical models of the plant multiplied by unit energy respectively. Input energy except fossil fuels such as nuclear energy for nuclear power or solar energy for renewable energy including potential energy for hydropower, has been omitted because they are "otherwise useless" or "renewable".

The term renewable refers to energy sources which regenerate themselves periodically or essentially inexhaustible. It covers a family of energy technologies that obey the principle of collecting and exploiting what nature would otherwise "waste" (**Haefele, 1981**). A renewable energy in "solar" derived, directly or indirectly.

Output energy is corresponding to the electricity generation of the plant subtracting the energy for the station service.

Total energy throughout its time has been calculated for input and output energy and compared with each other. The net energy ratio of output to input suggests the efficiency and reproductivity of fossil fuels into electricity for respective power plants.

The reasons of comparatively low value of the net energy ratio for some plants are as follows: for nuclear fuels high output energy of refining the nuclear fuels; for geothermal power, high input energy for reboring of the wells during operation; for wind power, low output energy because of low utility factor of the system; for solar cell, high input energy of refining the material of silicon as well as low output energy because of its short life of 5 to 10 years.

The net energy ratio of hydropower is outstanding among power plants due to the concentration of energy in the quantity and head of water by means of river system.

The unit emission of CO_2 per generated energy in kWh throughout the life of the plant including construction, operation and maintenance is also shown in Table 1. It has nearly the inverse inclination to the energy ratio. The difference of CO_2 emission among thermal plants exists owing to the component of carbon and hydrogen within the fuels, though it is substantially negligible in comparing with other sources of renewable energy.

The net energy ratio and unit CO_2 emission are shown also in Fig. 1. The original data of this analysis is offered with generous assent of Dr. Uchiyama et al. of the Central Research Institute of Electric Power Industry of Japan. The author of this paper has made a modification in life and load factor with occasional recalculation needed.

Table 2 shows the worldwide electricity generation in 1989. The portion of hydropower reaches to around 20% and the total generated electricity amounts to 11.4 millions MWH per annum.

The hydropower potentials are shown in Table 3 and Fig. 2 providing several region of the world with exploitable, developed and undeveloped portion respectively. In Europe and North America, the developed portions to the exploitable potentials are more than half. There remain, however, vast amount of undeveloped hydropower potentials in other regions. The total amount of exploitable energy of hydropower in the planet comes up to 13.9 million GWh exceeding the world generation of electricity in 1989.

Strictly speaking, there still lies a considerable uncertainty for the exploitable potentials because they are composed of the accumulation of the surveys of respective project.

TABLE 1

Net Energy Ratio and CO_2 Emission

Power Plants	Coal	Oil	LNG	Nuclear	Hydro	Geo-Thermal	Wind	Solar Cell
Input Energy (10 Kcal/kw)								
Construction (A)	0.75	0.58	0.58	0.97	5.11	3.82	11.95	25.54
Operation & Maintenance								
Fossil Fuel	14.49	14.49	14.49	-	-	-	-	-
Misl	0.77	0.65	2.52	0.79	0.05	0.49	0.05	0.05
Annual	15.26	15.14	17.01	0.79	0.05	0.49	0.05	0.05
Sub Total (B)	305.20	302.80	340.20	15.80	1.75	9.80	1.00	0.25 ~0.50
Total (C) = (A) + (B)	305.95	303.38	310.78	16.77	6.86	13.62	12.95	25.79 ~26.04
Output Energy (10^6 kcal/kw)								
Annual	5.23	5.31	5.45	5.46	3.38	4.20	1.58 ~2.76	1.25
Total (D)	104.60	106.20	109.00	109.20	118.30	84.00	31.60 ~55.20	6.25 ~12.50
Net Energy Ratio (E)=(D)/(C)	0.342	0.350	0.320	6.51	17.24	5.17	2.44 ~4.26	0.240 ~0.484
CO_2 Emission (g-c/kwh)								
Construction	0.95	0.83	0.75	0.83	3.88	3.56	19.55	243.84 ~121.92
Operation & M	9.80	7.33	32.67	6.26	0.93	8.49	11.18 ~6.39	11.78
Fossil Fuel	251.33	192.24	131.48	-	-	-	-	-
Total CO_2	262.08	200.40	164.90	7.09	4.81	12.05	30.73 ~25.94	255.62 ~133.70
(Note) Annual Load factor (%)	75	75	75	75	45	60	20~35	15
Life (Year)	20	20	20	20	35	20	20	5~10

TABLE 2

World Production of Primary Energy (1989)

Item	Portion of Consumption of Primary Energy
Solid Fuel	30.8 %
Liquid Fuel	41.9 %
Gas	22.7 %
Electricity	4.7 %
Total	100.0 %

(One equivalent = 7.43 x 10 9 ton)

TABLE 3

World Hydraulic Resource (GWH/Year)

oped Ratio		Exploitable Development Hydro Potential		Developed		Undevel-	
Asia	4 131 661	(29.7)	386 619	(18.1)	3 745 042	(31.8)	9.4 %
Africa	1 332 187	(9.6)	49 333	(2.3)	1 282 854	(10.9)	3.7 %
North America	968 982	(7.0)	572 986	(26.9)	395 996	(3.4)	59.1 %
Central & South	3 485 576	(25.0)	380 267	(17.8)	3 105 309	(26.3)	10.9 %
Europe	835 066	(6.0)	483 446	(22.7)	351 620	(3.0)	57.9 %
CIS	2 950 000	(21.2)	223 325	(10.5)	2 726 675	(23.2)	7.6 %
Oceania	202 595	(1.5)	37 288	(1.7)	165 307	(1.4)	18.4%
Total	13 906 06	(100.0)	2 133 264	(100.0)	11 772 803	(100.0)	15.4%

After Water Power 1989-90

Fig. 1 Net Energy Ratio & CO_2 Emission

– after Uchiyama et Al. –

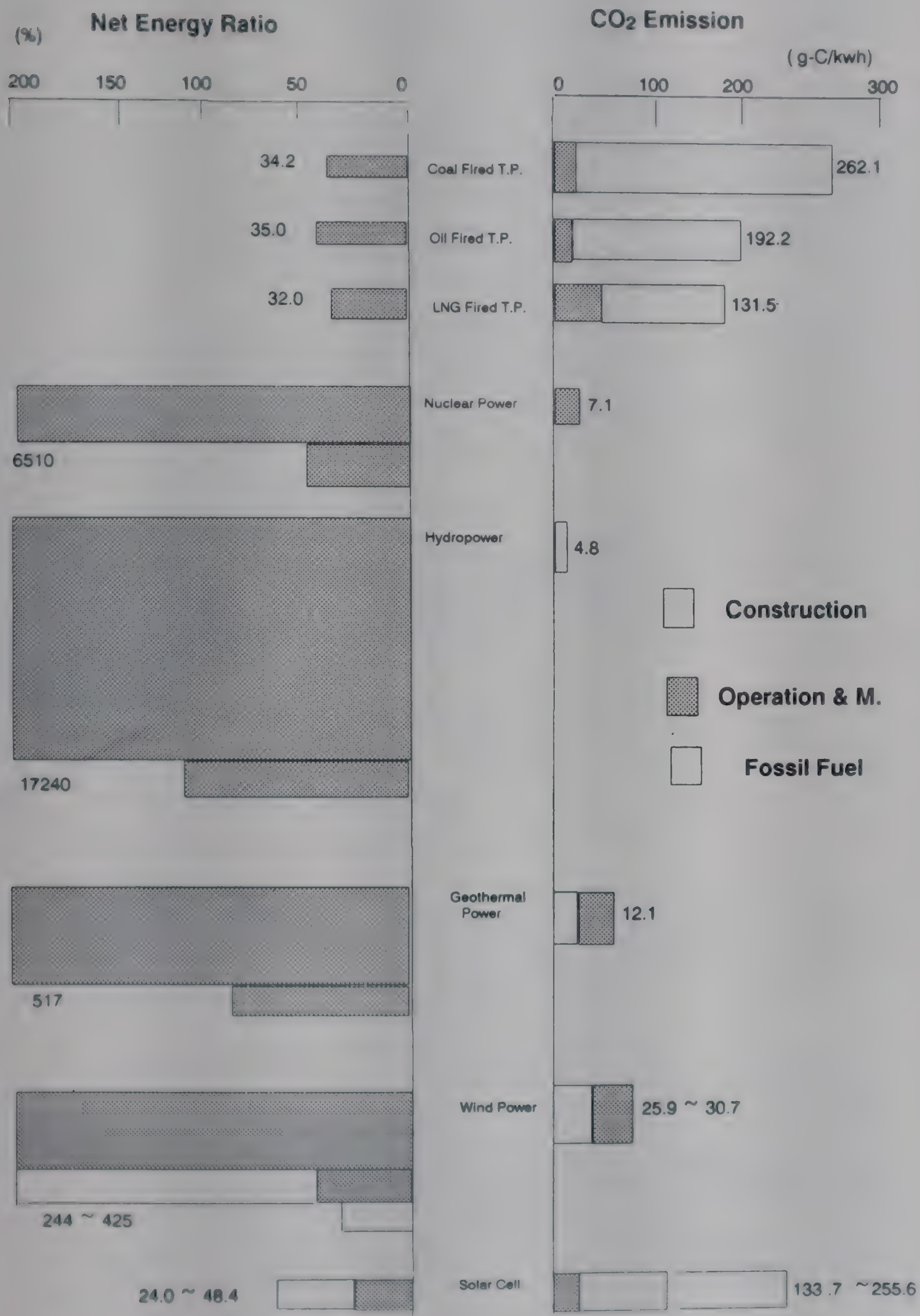
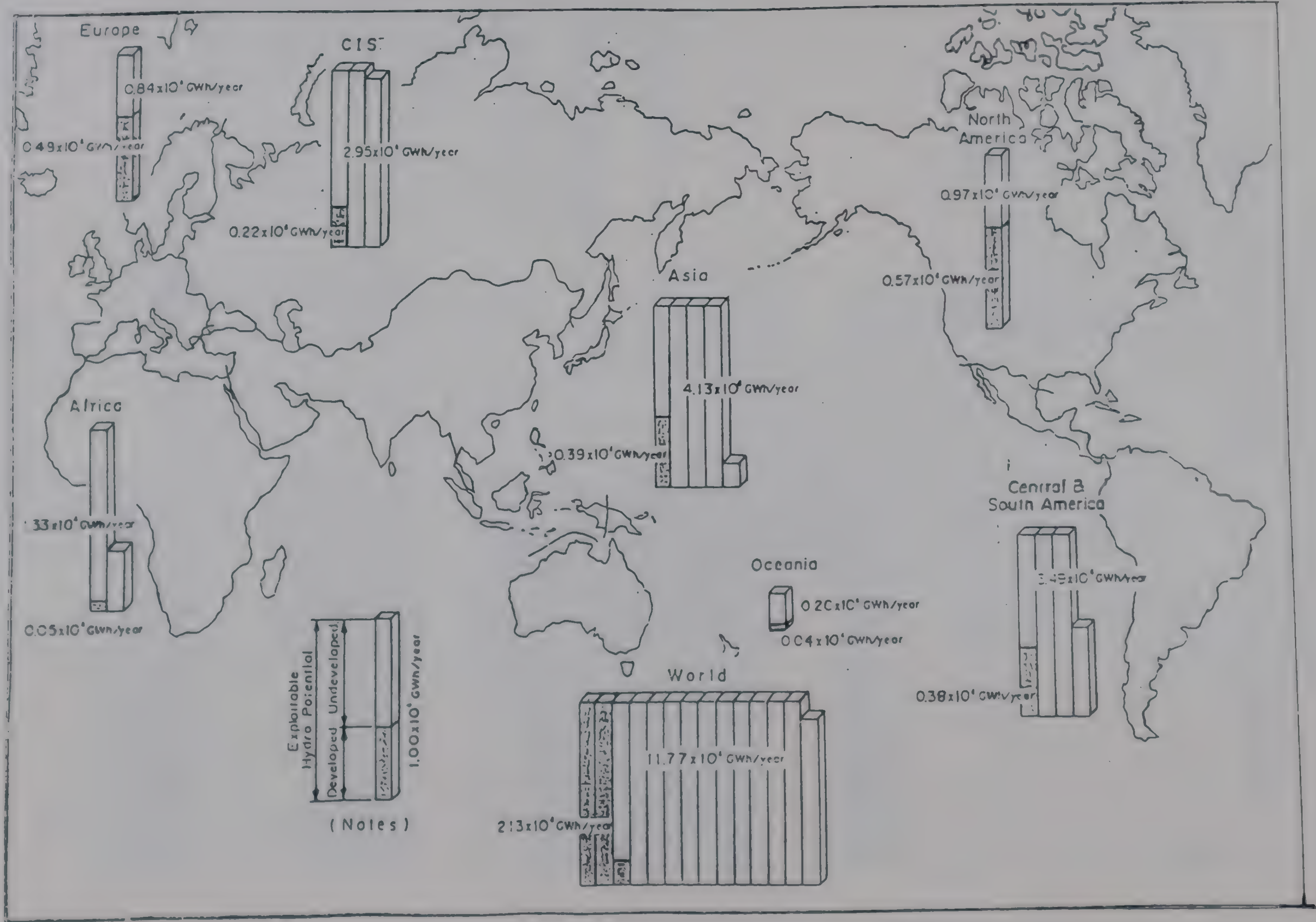


Fig 2. World Waterpower Potentials — After Water Power 1989-3



3. Basic Investigation

Owing to the characteristics of hydropower development that makes use of natural energy, it is substantial in planning the projects to expand investigations over such basic items as hydrology, meteorology, topography, geology, environment, etc. at each individual site. The investigation of global hydropower resources should be executed as follows:

The preparation works such as public acceptance of project area, financial guarantee, arrangement of organizations with international network, etc. are to be commenced beforehand. The collection of basic data will include the review of existing data, collection of new data by means of new technology such as remote sensing and telecommunications. The basic data may be composed of not only aforementioned natural data but those of demand and supply of electricity and social condition of construction and maintenance. A vast amount of data base of existing and newly collected basic data is expected to be composed as for the convenience of using computers.

It is essential to establish the methodology of evaluation or planning under the international discussion and agreement. The methodology is to cover such kind of scheme of development as object of global, regional, national or local supply of energy; type of reservoir, pondage or run-of-river; single or multi purpose development. The other items to be taken into account of the methodology are the appraisal of local conditions, environmental assessment and cost estimation.

Even though the hydropower development is harmless to the global environment compared to thermal power plants, it still possesses its own environmental problems to be assessed and solved. The dam and reservoir may bring issues such as inundation with deforestation, crisis of wild life, resettling, meteorological change or seismic movement and may also bring operation with sedimentation and eutrophication. The water conduits are to raise the drought of river. Other problems may be occur during construction and maintenance.

These environmental problems should be thoroughly assessed employing the experience and information of existing projects by an international network or organization.

4. Global Clean Energy Network System

(1) Transportation of Hydroelectric Power

As mentioned in the previous chapter, major undeveloped hydro potentials are located in low and high latitude areas in Asia, Africa, North and South America, and Siberia. As the locations of the hydro potentials are often far from major load centres, the electric power from the hydro resources is required to be transported in long distance, sometimes over the sea.

In order to transport electric energy, it is quite usual to utilise a transmission line. As an economy of a country grows, a power transmission network is being established. Moreover, there are some trans-country transmission networks which includes many international interconnections, as seen in Europe and North America. Some trans-country transmission networks are also growing in developing countries. However, a transmission system has limitations: When transmission distance increases, its economy and reliability are reduced because of increased construction cost, transmission loss and route troubles such as natural disasters and terrorism. Accordingly, a transmission system is hard to be applied in case of a overhead line, for example, over 1000 km of a submarine cable over several hundred kilometres.

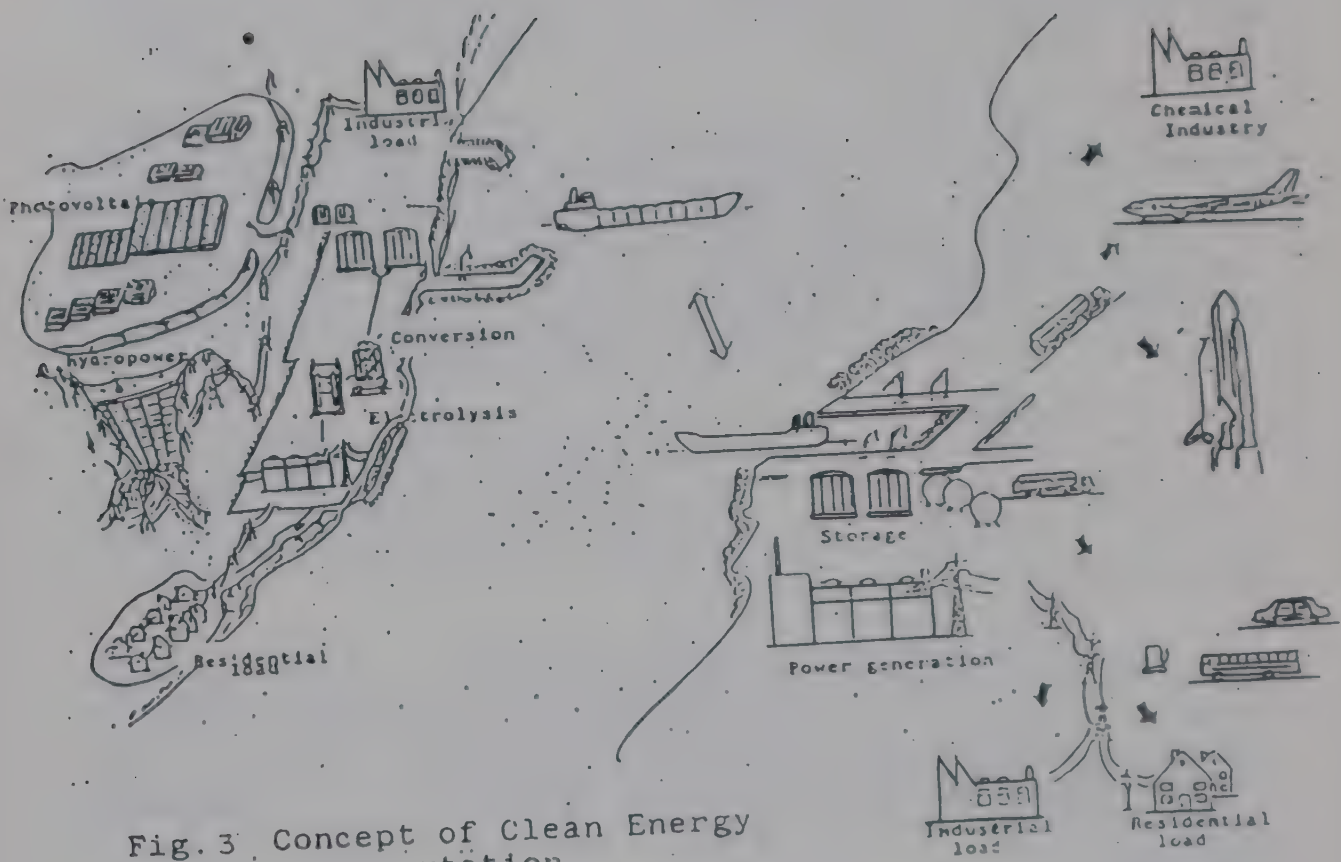


Fig. 3 Concept of Clean Energy Transportation

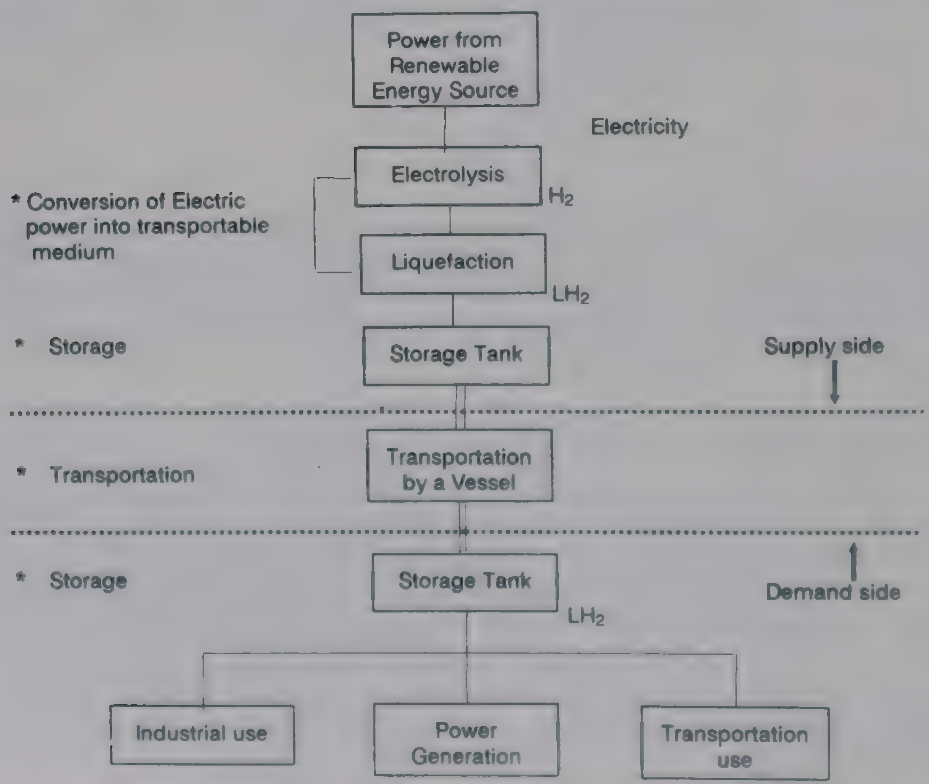


Fig. 4 : Example of Clean Energy Transportation Scheme
(The case of LH_2 Cycle)

In the cases that a transmission system is not applicable, the electric power generated by hydropower is expected to be transported to bulk energy consuming areas by vessels as in cases of petroleum and coal. In order to realize such a system, it is necessary to establish the following technologies and processes:

- Conversion of electric power into transportable medium
- Handling (transportation, storage etc.) of the medium
- Utilization of energy from the media

(2) New Energy Transportation Cycles

One of the most high-efficient conversion process from electric energy to chemical energy is to produce hydrogen through water electrolysis process. Hydrogen is applicable to various kinds of chemical reactions and is expected to produce a certain medium which is adaptable for energy transportation. Therefore, we decided to search for a renewable energy transportation technology or "clean energy transportation" which begins with water electrolysis. We searched for the media for energy transportation among varieties of matters including inorganic and organic ones. For the selection of the media, we establish the following set of criteria and identified the energy transportation cycles as shown in Table 4.

- to be liquid under the temperature and pressure conditions of transportation and storage
- to have high hydrogen content ratio (for example, more than 5 weight - %)
- if organic, to achieve chemical equilibrium with a low reaction head and high conversion rate under practical temperature and pressure conditions.
- to generate no CO_2 in the whole cycle, or less than the existing system
- to have high adaptability to the existing energy system.

TABLE 4

Candidate Energy Transportation Cycle

1	LH_2	a. H_2	->	LH_2	(Liquefaction)
		b. LH_2	->	H_2	(Evaporation)
2	CH_3OH/CO_2	a. $3H_2 + CO_2$	->	$CH_3OH + H_2O$	
		b. $CH_3OH + H_2O$	->	$3H_2 + CO_2$	
		CO_2 recovery and requefaction			
3	CH_3OH/CO	a. $2C + O_2$	->	2 CO	(Coal Gasification)
		$2CO + 4H_2$	->	$2CH_3OH$	
		b. $CH_3OH + H_2O$	->	$3H_2 + CO_2$	
4	CH_3OH/HCO	a. $2H_2 + HCOOCH_3$	->	$2CH_3OH$	
		b. $2CH_3OH$	->	$2H_2 + HCOOCH_3$	
5	AMMONIA	a. $3H_2 + N_2$	->	2NH3	
		b. $2NH_3$	->	$N_2 + 3H_2$	
6	CYCLOHEXA	a. $3H_2 + C_6H_6$	->	C_6H_{12}	
		b. C_6H_{12}	->	$3H_2 + C_6H_6$	

a : Process at supply side
b : Process at demand side

(3) Pre-feasibility Study

In the pre-feasibility study, the six candidates were compared economically and technically. For economic analysis, construction and O&M costs were estimated based on the assumptions presented in Table 5.

TABLE 5

Assumptions for Economic Analysis

1	Plant capacity	Overseas electric power input of 1000 & 4000 MW
2	Overseas Power cost	2-5 Yen/Kwh (Approx. 15 - 35 mil/kwh)
3	Transportation milage	5000 km and 10 000 km
4	Electrolysis efficiency 90 %	
5	Fixed charge rate	25 % for plant facilities 21 % for a vessel

Table 6 compares the technical and cost features of the clean energy transportation cycles for the cases of the power generation of 4000 MW at supply side and the distance of 5000 km.

Table 6

Technical features of energy transportation cycles

	LH2	CH_3OH/CO_2	CH_3OH/CO	$HCOOCH_3$	NH_3	C_6H_{12}
H2 production (100 NM3/h)	800	913	885	932	856	984
Medium Pro'n (t/day)	1714	10438	151788	31945	10540	7384
Tank capacity (1000m3xunit)	19 x 9	94.5x1 13.5x7	103 x 1	95 x 3 111 x 2	53 x 2	87.5 x 3 87.5 x 3
Vessel cap (1000m3xunit)	110x4	63 x 4	205 x 2	148 x 5	69 x 4	175. x 4
Transported Energy (Gcal/h)	2370	2350	3990	2380	2360	2270
Efficiency	70 %	68 %	66 %	69 %	68 %	60 %
Capital cost (MUS$/Gcal/h)	2.1	1.9	0.92	1.2	0.84	1.0
Energy cost E = 1.5 E = 3.8	 9.1 12.8	 9.8 13.0	 4.9 7.2	 8.2 12.0	 5.4 9.4	 7.1 11.2

UScents/Mcal

Note E : Power rate from renewable enregy source at supply side (UScent/kwh)

Transported energy : Energy of H_2 of CH_3OH at demand side

Efficiency : Output energy/Input energy; McOH reformation energy of CH_3OH/CO cycles, dehydrogenation energy of NH_3, C_6H_{12} and $CH_3OH/HCOOCH_3$ cycles are subtracted from output energy.

The comparison of the results of each energy transportation cycle is summarized as below:

- Energy transportation efficiency is 70% or a little less excluding Cyclohexane cycle's 60%.

- Capital costs of CH_3OH/CO and NH_3 cycles are the lowest, being followed by those of $CH_3OH/HCOOCH_3$ and C_6H_{12} cycles. Capital costs of LH_2 and CH_3OH/CO_2 cycles are the highest.

- Transported energy costs have the similar tendency to the capital costs.

The comparison of the maturity of technologies required for each cycle is summarized as below:

- For LH_2 and CH_3OH/CO cycles, major technologies are nearly established excluding scale-up of plant capacity.

- For CH_3OH/CO_2 cycle, CO_2 recovery at demand side and hydrogenation process at supply side are in the research level.

- The dehydrogenation processes of NH_3 and C_{6H12} cycles at the demand side and the hydrogenation process of $CH_3OH/HCOOCH_3$ cycle are not established industrially.

From a view point of environmental issues, all the cycles are CO_2 emission free through the total cycle process, excluding CH_3OH/CO cycle which has the 40% reduced CO_2 emission as compared with a coal power plant. Because the f el extracted from the medium, H_2 and CH_3OH, are quite pure, the other emissions such as SO_x and NO_x will be quite limited as compared with conventional system.

5. Proposal of International Cooperation

(1) Investigation of Worldwide Hydropower Resources

The hydropower development is outstanding and essential for the sustainable development of the world with alleviation of global environmental problems, as described in the foregoing. The present situation for the development of hydropower, however, remains that only a small portion of the exploitable potentials has been developed with an enormous amount of undeveloped resources especially in developing countries. There is an insufficiency of basic investigations necessary for planning and programming project. Since the past surveys have been carried out by various agencies in various agencies in various countries based on their specific criteria and precision levels and compiled together, then the reliability of the surveys is not sufficient to regard them the global hydropower potentials. Also in order to attain the best energy mixture at global levels, the potentials of hydropower resources should be investigated with higher accuracy and consistency.

For the promotion of future hydropower development, it is proposed to reevaluate the significance of hydropower energy under a new framework of global standpoint. The evaluation criteria should be established taking into account present and future limitations of resources, environmental constraints, technological innovations, etc. According to this criteria, the basic investigations of the worldwide hydropower resources should be implemented.

(2) Global Clean Energy Network System

The pre-feasibility study has shown that the clean energy transportation cycle, is well within the reach in terms of technology. From the viewpoint of economy, the energy cost is expected to fall within an acceptable range, especially because we live in the age when various kinds of values are changing including those on the energy and environmental issues.

The significance of the clean energy transportation scheme is, firstly, one of the energy technologies responses to global environmental challenges through redistribution of energy resources, secondly, the diversification of energy sources at the energy demand side, and, thirdly, the redistribution of income and establishment of infrastructure through energy development and transactions. The scheme is considered to be worth being continuously challenged from various viewpoints, in order to eliminate the limitations of existing power transmission or energy transportation technology.

From the viewpoint of technology, the scheme, being the energy supply system, is required to be efficient, reliable, economical and mild to environment. In order to identify the best energy transportation cycle, it is desirable that we should proceed to the next stage of R&D, for example a bench scale test and a pilot plant test. Among the various technologies, the establishment of Solid Polymer water electrolysis process is important because it is required for every cycle.

From the social viewpoint, when the scheme is realized, the new energy medium, H_2 or CH_3OH, will largely affect the energy demand-supply system and social system itself. In the selection of the transportation cycle, various kind of its influences to society and ecosystem should be studied, including transitional stages energy supply system. For example, it is desirable that the transported energy should be utilised for power generation or city gas, because they require less investment of infrastructure than that of small scale energy demands such as vehicles.

From the viewpoint of international consensus, the policy of redistribution of renewable energy resources should be discussed, assuming the new energy transportation technology. The discussion should also include the demand-supply balances of each country to identify the reasonable energy surplus of each country.

6. Conclusion

Under the consideration of the significance of hydropower development for the sake of sustainable development, an international cooperation of the worldwide investigation, the R&D of transportation of electricity utilizing hydrogen and the organization and finance of promotion of development, is to be an absolute necessity for our common future.

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HYDROGEN ECONOMY

Rana, K.N., et al.

1. Introduction

The importance of hydrogen as a chemical intermediate began with the advent of petrochemical industry and it is today manufactured in bulk quantity all over the world. Hydrogen is the principal raw material or feedstock for the production of ammonia, methanol and oxochemicals. It is also used in hydro treatment of mineral oil and petroleum refining. Further, a substantial quantity of hydrogen will be needed for upgrading shale oil and for the gasification of coal in future. Hence the steady growth in industrial demand for hydrogen is expected to continue unabated in the next century.

Despite the high tonnage production and consumption of hydrogen as a chemical feedstock, it traditionally serves as a fuel only in certain specialized applications, such as oxyhydrogen cutting and welding torches. The single largest use of liquid hydrogen as a fuel has been in rocket propulsion in the space programme. But hydrogen has lately attracted widespread interest after the 1973 "oil crisis", particularly because it is an excellent candidate for acceptable, permanent energy source for universal application due to the following reasons:

a) Hydrogen can be produced from water which is abundantly available;

b) Its combustion yields water i.e., its own raw material which can be infinitely recycled;

c) It can substitute petroleum products such as petrol, diesel, kerosene and fuel oil including as an engine fuel without extensive re-equipment;

d) It is an exceptionally clean fuel since its combustion in air will generate only nitrogen oxides and water, but not sulphur dioxide and other "green house" gases such as carbon dioxide and carbon monoxide (the amount of nitrogen oxides produced is also much lower for hydrogen than for other fossil fuels); and

e) Hydrogen is an easily manageable fuel and under normal industrial practices it is not considered more hazardous to use other than conventional fossil fuels.

Hydrogen is thus a non-polluting and environmentally sound energy alternative in the world. But the single largest drawback of hydrogen is its storage. Gaseous hydrogen is costly to store and transport due to its low energy density. It can, however, be compressed, liquefied or stored as a metal hydride. Needless to say, the handling and storage cost for a highly compressed hydrogen gas or for its cryogenic-storage facility is rather very high whereas the metallic hydride technology is still under research and development stage.

2.1 Global Concept of "Hydrogen Economy"

The immediate oil supply constraint faced during 1973 "oil crisis" as well as the increasing long range concern over global energy supply have accelerated the scientific and economic interest in hydrogen as an energy alternative at the global level. This development has given birth to the global "Hydrogen Economy" concept. As the fossil fuels

will be exhausted, the future energy supply will have to be harnessed from other sources such as nuclear and solar energy. The "Hydrogen Economy" concept offers hydrogen as the universal energy form for transmission, storage, delivery and use due to the apparent advantages of this fuel specified earlier. In this scenario, electricity will be generated from large-scale primary energy sources (nuclear/solar/wind/geothermal/tidal/etc) at great distances from the load centres and it will be converted into hydrogen gas by conventional electrolysis of water or by any other new technologies such as thermochemical process, photolysis, etc. This hydrogen gas, which has to serve as an energy transfer mechanism between centrally generated electricity and various other end-uses, will then be transmitted by underground pipelines and stored in underground systems which will be similar to natural gas containing "gas wells[1]". The hydrogen gas will be transmitted by pipeline to the consumer centres where it will be cryogenically stored in liquid form above ground[2]. It is envisaged that the liquid hydrogen will serve the end-users such as local power stations, industries (as fuels, reducing gas or chemical feedstock) as well as domestic consumers. This is in essence the global "Hydrogen Economy" concept.

It has been pointed out time and again that from the scientific viewpoint this concept is essentially sound. But the realization of this concept is entirely another proposition since it implies not only the need for vast research and development efforts but also the willingness to undergo severe engineering and economic changes at the global scale. In reality, the actual pace of hydrogen energy technology development and use may depend, among others, upon following factors (1):

a) the economic and environmental performances of hydrogen over other competitive energy sources;

b) the technological advancement in related fields upon which hydrogen system may depend; and

c) the unilateral development efforts on behalf of hydrogen oriented systems.

It has been reported that "the interest of potential users with large resources for R&D has made hydrogen technology one of the most active areas of energy research in the past decade. It has evoked interest in Brazil, China and India among developing countries" (2).

2.2 Global Issues of Hydrogen Economy

The extent and the time-scale on which hydrogen will ultimately become primary fuel is largely dependent upon three factors, namely, the economics of hydrogen production, distribution and application in relation to the economics of other competing energy sources. Nevertheless, the relative environmental impacts and use-hazard assessments of different energy sources, which are usually secondary considerations, may have important implications for hydrogen use.

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1 The storage of 30 billion standard cubic feet of helium gas at Amarillo, Texas, in a partially depleted natural gas field has been cited as an example of such storage.

2 Again the 900,000 gallons liquid hydrogen storage tank at the Kennedy Space Flight Centre at Cape Canaveral, Florida - the largest tank in existence - is cited as an example in this context.

The global problems and prospects of hydrogen economy can be presented under different perspectives. Needless to say, a static analysis under the technological status quo for hydrogen related technologies will render the hydrogen economy a pessimistic outlook, the global environmental deterioration (climatic change, sea level rise, acid rain, etc) being the only favourable factor for its wide-scale energy application in near future. On the other hand, an analysis in the dynamic context with new technological developments presents a bright future for hydrogen as a primary fuel in the global economy in not-so-distant future. These aspects will be elaborated at some length below.

First of all, let us examine the pessimistic view which states that hydrogen may not be a competitive substitute to fossil fuels in the foreseeable future. The logic behind this line of reasoning is straight forward. The cheapest way to manufacture hydrogen today is through steam reformation of hydrocarbons such as natural gas, refinery gas, naphtha, etc. On the other hand, the conventional electrolysis of water is a very expensive process even if it yields 99.9 percent by volume pure hydrogen due to electricity consumption by electrolysers as well as high electricity tariffs. Since the hydrogen is manufactured from the hydrocarbon raw materials, it will be inevitably more expensive than the hydrocarbon raw materials themselves. That is why hydrogen cannot today economically compete with liquid petroleum fuels such as petrol, diesel and kerosene in the global market. As the price of oil and natural gas will escalate with the depletion of their reserves in future, hydrogen obtained from the steam reformation of hydrocarbons again may not be able to compete economically with natural gas. This is because natural gas can be used as easily as hydrogen in engines and it is also cheaper to transport than hydrogen is due to more energy content[3]. These considerations indicate that hydrogen may not emerge as a competitive fuel as long as oil or natural gas will remain the dominant forms of energy in the global market, except in small, specialized markets (such as steelmaking, cutting and welding).

If we extend this scenario beyond the time when both oil and natural gas reserves will be exhausted or their prices will escalate prohibitively, then coal is likely to come in the forefront as the dominant form of energy and replace both of them. But coal is not expected to be used in its natural form at that time. It will be most likely processed to yield liquid (coal liquefaction) or gaseous (synthetic natural gas) fuels including hydrogen. In this case, the coal-based synthetic oil and methanol are liquid fuels with higher energy density than gaseous hydrogen and as such they have distinct advantage over hydrogen for storage and transportation. Thus hydrogen economy may have to await until coal mines will also be exhausted or the coal extraction cost will increase prohibitively. Given the large world reserves of coal, the prospect of hydrogen as an energy alternative indeed appears only in a very distant future, if at all under the static concept.

The scenario presented above may,. however, dramatically change on favour of hydrogen economy if the global environment problems due to climatic change (green house effect, acid rain, rise in sea level, etc) will lead to restrain fossil-fuel consumption. At present, there is considerable controversy regarding whether or when this will happen and also how much environmental degradation is actually tolerable. The proposed UN Conference on Environment and Development which will be held in Brazil in June, 1992 may reach some consensus in this respect. The prospect of hydrogen economy will

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3 Natural gas (methane) contains three times more energy than hydrogen. The lower heating value of hydrogen is about 10.4x103KJ/m^3 while that of natural gas is about 37.3x103KJ/m^3. Thus to transmit an equivalent amount of energy, about 3 time more hydrogen has to be transported. Although the flow capacity of hydrogen nearly compensates for this difference, the compression cost for hydrogen is much higher than for natural gas.

substantially improve in the public opinion will turn against fossil fuels as strongly as it did against nuclear power in industrialized countries during 1970s and 1980s. Under these circumstances, hydrogen will have to be produced from water since the combustion of fossil fuels will be environmentally undesirable regardless of their low cost.

The production of hydrogen from water requires a huge quantity of energy, whichever process may be considered for this purpose. Hence the generation of abundant and cheap source of energy is the precondition for hydrogen economy which will have to depend upon nuclear power, off-peak electricity, and solar energy in future.

Now let us examine the second view which is more optimistic. The dynamic analysis considers the possible technological developments in the production, transportation and use of hydrogen as an energy alternative. It is apparent that the prospect of hydrogen economy may substantially improve even without the environmental deterioration factors due to the present R&D efforts on hydrogen technology. Some of the major developments which are likely to improve the hydrogen economy are described are presented below (3,4):

a) **Improvement in Electrolytic Cells**

The performance of conventional electrolyzers has substantially improved in recent years. Commercial electrolyzers today operate at efficiencies ranging from 70 to 90 percent. It is expected that advanced electrolyzers using high pressure and/or temperatures will achieve 95 percent efficiency in near future.

b) **Development of New Processes for Hydrogen Production**

The development of new processes for hydrogen production is the main area of research in all advanced countries. There are several new processes under consideration such as direct thermal process, thermochemical process and photolytic process. All these processes intend to split water into its basic components, namely, hydrogen and oxygen. Considerable research efforts are directed in this area both in Europe and USA. The possible breakthroughs in these technologies could make hydrogen a cheap source of energy in future.

c) **Storage of Hydrogen**

Hydrogen storage is another area of recent development. While large-scale storage of gaseous hydrogen has already been practised in France (aquifer) and U.K (salt mine caverns), small-scale storage is undertaken as pressurized gas in lightweight high strength containers. The recent development of magnetic liquefaction process has cut down the price of liquid hydrogen by 50 percent. Further, metal hydride storage technology is the main area of current research which has already produced several practical hydrides for hydrogen storage.

d) **Transmission and Distribution of Hydrogen**

Commercial hydrogen pipelines already operate in USA (96 Km), U.K (16 Km), France and Germany (over 600 km). It has been reported that hydrogen is cheaper to transport than electricity today over a distance of 200 miles. Liquid hydrogen is also transported today in large dewars by rails and trucks.

e) **Utilization of Hydrogen**

Hydrogen is today experimentally utilized in many applications such as power generation, industrial steam supply, residential energy supply and transportation. For electricity generation, two important developments have taken place in recent years. First of all, it is the development of hydrogen oxygen steam generator with nearly 100 percent efficiency to replace the fossil-fuelled plants. The second development is in fuel cells which have achieved up to 70 percent efficiency for electricity production and further research is expected to yield up to 90 percent efficiency. The hydrogen oxygen generator mentioned above is also ideal for industrial steam supply. Hydrogen has recently been used in many experimental applications for heating, water heating, water pumping, domestic cooking, refrigeration, lighting, washing machine operation, etc. The concept of hydrogen home has also been translated into reality. Finally, hydrogen has found research application mainly in transportation e.g., space travels, airplanes, automobiles, and also in trains and ships.

As stated earlier, the technological developments mentioned above are likely to improve the hydrogen economy dramatically. But there is considerable uncertainty regarding the time-scale even under this dynamic perspective, particularly because the developed countries who are at present undertaking the bulk of research on hydrogen technologies do not show any urgency for the deterioration, however, may dictate otherwise and thus provide the required impetus for the large-scale development and application of hydrogen as a fuel at the global scale.

3. Appropriateness of Hydrogen as a Fuel in Various End-Uses

The physical and thermochemical properties of hydrogen demonstrate that it is a very unusual type of fuel. Hydrogen is used as fuel in gaseous, liquid and hydride forms so that it is necessary to examine its properties in all forms. The physical and thermochemical properties of hydrogen are compared in Table 1. with petrol and natural gas (which has methane as its main constituent). It is apparent that the gravimetric heating value of hydrogen is superior to that of natural gas and petrol. The volumetric heating value, however, is lower in gaseous form, but higher in liquid form than both the above mentioned fuels. These properties of hydrogen are also confirmed by its broader comparison with other conventional fuels such as petrol, fuel oil, kerosene, jet fuel, ethanol, methanol, methane, ammonia, propane and butane in Table 2. Hydrogen thus shows a distinctive feature as a fuel and under equivalent physical conditions, it has the largest energy per unit mass and lowest energy per unit volume.

TABLE 1

Physical & Thermochemical Properties of Hydrogen, Natural Gas & Petrol

	PROPERTY	HYDROGEN	NATURAL GAS	PETROL
1	Density(g/cm^3)	8.4×10^{-5}(Gas) 0.071 (Liquid)	7.8×10^{-4}	0.73
2	Boiling Point (°C)	-253	-156 (20 K)	38-204
3	Lower Heating Value : a) Gavimetric (KJ/Kg) b) Volumetric (KJ/m^3)	 12.54×10^4 10.4×10^3(gas) 8.52×10^6(Liquid)	 4.8×10^4 37.3×10^3	 4.45×10^4 32.0×10^6
4	Stoichiometric composition in Air (Volume %)	29.3	9.43	1.76
5	Flammability limits (% IN Air)	4-75	5-16	1.4-7.6
6	Flame Speed (m/sec)	3.45	0.41	0.4
7	Flame Temperature in Air (C)	2,045	1,875	2,197
8	Ignition Temperature (°C)	585	540	257
9	Flame Luminosity	Low	Medium	High

Source : Veziroglu T.N (3)

TABLE 2

Combustion Energies per unit Mass and per unit Volume for Selected Fuels

	Fuel	Density (g/cm 3)	Approx Energy Unit Mass (J/g)	Approx Energy Unit Volume (J/cm 3)
1	Petrol	0.735	44800	32800
2	No 2 Diesel Fuel	0.838	44400	37250
3	Kerosene	0.821	44800	36300
4	JP-4 (Jet Fuel)	0.777	43550	34100
5	C_2H_5OH (Ethanol)	0.789	27100	21500
6	CH_3OH (Methanol)	0.795	20500	16150
7	CH_4(g)2_/ (Methane)	0.136	50250	6850
8	CH_4(g)3_/ (Methane)	0.425	50250	21350
9	NH_3(1)1_/ (Ammonia)	0.635	18850	11900
10	C_3H_8(1)1_/ (Propane)	0.579	46500	27100
11	C_4H_{10}(1)1_/ (Butane)	0.563	46050	26050
12	H_2(g)2_/ (Hydrogen)	0.017	121400	2100
13	H_2(1)3_/ (Hydrogen)	0.017	121400	8600
14	$MgH_2$4_/ (Magnesium Hydride)	0.87	8650	7550
15	$VH_2$5_/ (Vanadium (Hydride)	6.4	2550	16400

Notes :

1_/ Liquid at 27°C (80°F)
2_/ Gas at 27°C (80 F) and 204 ata (3000 psig)
3_/ Liquid at cryogenic tempratures and 1 ata
4_/ Magnesium hydride bed with 40 percent voids at 260 C (500 F)
5_/ Vanadium hydride bed at 10°C (50°F)

Source : Penner S.S. and Icerman L; Energy Vol II (5). Abridged.
Conversion factor : 1 calorie = 4.1868 Joule.
Figures are rounded off to nearest fifty.

Hydrogen has also excellent combustion parameters i.e., properties related to the kinetic aspects of its use as fuel. First of all, hydrogen has very wide flammability limits. The hydrogen - air mixture is capable of burning in a wide range of composition limits (approximately 4.0 to 75.0 volume percent for lean and rich limits near room temperature). This is a desirable property for combustion applications since it allows operation even under conditions of imperfectly controlled hydrogen-air injection. But, side by side, this particular property of hydrogen presents a potential hazard when accidental leakage occurs. Needless to say, the flammability limits are a function of temperature and they become much wider at elevated temperatures e.g., 7.0 to 79.0 volume percentage at 300°C as compared with 9.0 to 73.5 volume percentage at 100°C (5).

The minimum ignition energy which is the energy supplied by a spark to initiate burnings another important combustion parameter. A hydrogen-air stoichiometric mixture has much lower minimum ignition energy at atmospheric pressure (0.019 millijoule) than the corresponding value for a stoichiometric methane-air mixture (0.29 millijoule). Thus hydrogen combustion is much easier to initiate than methane or natural gas combustion. There is, however, an ignition lag which depends upon a host of factors such as temperature, gas composition and surface condition to reaction vessels.

The quenching distance, the maximum distance between which the combustion is suppressed, is another important combustion parameter. Here again, the minimum value for a stoichiometric hydrogen - air mixture at 1 atmosphere is about 0.064 centimetres whereas the corresponding value for methane is 4 to 5 times greater (5). This implies that hydrogen combustion will be more difficult to quench (or easier to sustain) than natural gas or methane combustion. The quenching distance property in conjunction with the minimum ignition energy requirement for hydrogen - air mixture noted above shows that hydrogen is not only easier to ignite but also more difficult to quench than methane or natural gas.

The flame velocity or burning velocity - the rate at which a flame propagates into a combustible gas mixture - is the next important property of combustion. Once again, the hydrogen-air mixture has an exceptionally high flame speed more than 300 centimetres per second for gas initially at 300°K and atmospheric pressure) as against the corresponding values (34 to 45 centimetres per second) for methane-air, butane-air and petrol-air mixtures (5,4). The hydrogen-air mixtures will thus burn very quickly due to high flame speed and, therefore they will need very small combustion chambers than in case of other conventional fuels.

The flame temperature of hydrogen-air mixture (2,045°C is higher than for methane-air (1875°C) but lower than petrol-air mixture (2,197°C). Thus hydrogen-air flames have relatively high temperature, but this disadvantage could be practically eliminated by operating at off-stoichiometric mixture compositions.

Finally, the experimental results in single-cylinder engine show that the hydrogen-air mixtures generate much less NO_x than petrol-air mixtures at preferred compositions (5). In fact, fuel-rich hydrocarbon mixtures yield high emissions of carbon monoxide and organic chemical residues whereas fuel-rich hydrogen mixtures give low emissions of NO_x but increased emissions of hydrogen and ammonia from the automobile engines (5).

The combustion properties of hydrogen discussed above are generally superior to the properties of other conventionally used fuels such as petrol and natural gas. Hence hydrogen can be used more economically than other conventional fuels, particularly due to its wide flammability limits, minimum ignition energy, high flame velocity, etc. But the use of hydrogen as a fuel necessitates design modification of combustion equipment. While

both the petrol and diesel engines can be adjusted to hydrogen fuel, major modifications will be required in conventional internal combustion engines. Similarly, burners and cookers will also require design modifications, in conventional appliances.

The storage of hydrogen has important implications for its application. Hydrogen as a fuel can be stored in one of the following three ways: (a) as a compressed gas (GH_2); (b) as a cryogenic liquid (LH_2); and (c) as a metallic hydride (MH_2). Storage of hydrogen gas in pressurized steel cylinders is a common industrial practice up to 340 atm (5,000 psi). But since hydrogen is the lightest element with specific gravity of 0.0695 g/l, the storage capacity required for this gas even at elevated pressures will be quite large which may restrict the use of this storage in many applications. On the other hand, storage of hydrogen as a cryogenic liquid is also a common practice in industry. But since the boiling point of hydrogen is very low (20.39°K or about -253°C at 1 atm), tanks for such storage are generally double-walled with a good vacuum drawn between the walls to reduce conductive heat leakage. The largest example of such LH_2 tank in existence is at the Kennedy Space Flight Centre at Cape Canaveral, Florida, USA[4]. The standard design consists of a spherical storage container in which the inner shell is made of steel or aluminium and the outer shell is made of carbon steel with the evacuated jacket containing perlite as insulation. Hence, even in case of liquid hydrogen (LH_2), there are considerable storage problems: a) the need for relatively large storage volume due to the low density of liquid hydrogen (0.071 g/cm^3 at 20.4°K); b) the necessity to construct specialized storage container with heavy insulation and maintain very low temperature (20.39°K or -253°C); and c) the need to ventilate the vaporization losses from the tank, which may perhaps amount to 2 percent or more per day, so as to avoid the ignition of vented hydrogen gas or accumulation of explosive hydrogen-air mixtures. The dispersion of vaporization losses, however, may not be a serious matter provided adequate provision for ventilation will be considered since hydrogen as the lightest gas will rise and diffuse rapidly.

Cryogenic technology, however, has rapidly advanced in recent years. Liquid hydrogen (LH_2) is today stored and transported in superinsulated vacuum dewars and for a 150-litre container, the loss of hydrogen is only 2 percent per day; if the jacket is cooled by liquid nitrogen then the loss will be only 1 percent per day. The larger vessels have correspondingly smaller losses due to the decrease in the ratio of surface area to volume. For example, stationery dewars of 5,000 -litre capacity have a loss rate of 0.85 percent per day. Liquid hydrogen is also shipped by trucks in semitrailer dewar tanks with a capacity of about 3,773 kg (8,000 pounds) per dewar with boil-off of about 0.5 percent per day. Liquid hydrogen is also shipped in railroad tankcars with a capacity of about 7,727 kg (17,000 pounds) each (1).

Metal hydrides (MH_2) offer an alternative approach to hydrogen storage. Since hydrogen penetrates the lattice structure of solid metals and alloys due to its small molecular size and high diffusivity, the concentration of hydrogen per unit volume in some metals, such as titanium, is actually greater than in liquid hydrogen. Further, the exothermic hydride reaction, which is formed by exposing the metal to hydrogen under pressure, is reversible and the hydrogen can be recovered by the application of low-

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4 The NASA Kennedy Space Centre Lunch Complex 39 facility has a capacity of 900,000 gallons and a boil-off of 0.03 percent per day which means the holding capacity is greater than 9 years. The energy capacity of this single tank is about 75 percent of the capacity of the World's largest pumped hydro-electric storage plant at Ludington, Michigan, USA (6).

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temperature heat such as waste heat from the combustion of a vehicle. Considerable research is at present going on in this area in advanced countries. Although magnesium hydride was the earliest to be studied, meanwhile many other promising materials have been identified which can be grouped into: a) monohydrides and dihydrides of vandium and niobium (columbium); b) hydrides based on rare-earth metal together with iron, nickel, cobalt, or copper; and c) hydrides formed with an intermetallic compound containing iron and titanium. Since the hydrides proposed so far involve high cost metals, the storage tanks made from these metallic hydrides will be expensive. The development of hydride technology thus offers high potential for hydrogen storage (Table 3).

TABLE 3

Comparision of Hydrogen Storage Media

Medium	Hydrogen Content (WT%)	Storage Capacity (g/ml of vol)	Energy Density Heat of Combustion Cal/g	Cal/ml of vol
A. HYDRIDES				
MgH_2 1_/	7.00	0.101	2373	3423
$MgNiH_4$	3.16	0.081	1071	2745
VH_2	2.07		701	
$FeTiH_{1.95}$	1.75	0.096	593	3245
$TiFe_{.7}Mn_{.2}H_{1.9}$	1.72	0.090	583	3050
$LaNi_5H_{7.0}$	1.37	0.089	464	3051
$R.E.Ni_5H_{6.5}$	1.35	0.090	458	3050
Liquid H_2	100.00	0.070	33900	2373
Gaseous H_2 (100 atm)	100.00	0.007	33900	244
N-Octane			11400	8020

Notes : 1_/ Starting alloy 94% Mg 6% Ni
2_/ Refers to H only in metal hydrides

Source : Veziroglu T.N. (3)

4. International Trend in Hydrogen-related Technology Development

The current trend in hydrogen-related technology development outlined here is, by no means, exhaustive. In fact, this topic is one of the main theme for the forthcoming Expert Group Meeting which will be held in July, 1992 at Kathmandu. Nevertheless, an attempt is made here to outline the general trend in international R&D activities for hydrogen application as an energy alternative.

Hydrogen has evoked considerable interest in all advanced countries and Brazil, China and India among developing countries. The concerted effort to use hydrogen as a fuel has just started due to high calibre research works undertaken in this field which have produced remarkable results. Although hydrogen can directly serve as a fuel for heat, power and light, the literature research suggests that it has received attention primarily for automotive and space use until a few years ago.

4.1 Automotive Use

From the technical viewpoint, hydrogen is an excellent fuel to substitute hydrocarbons (petrol, diesel, kerosene, etc) in automotive use. It can be conveniently handled and stored as hydrocarbons. Hence liquid hydrogen (along with liquid oxygen) has been a favourite fuel in applications where cost is not a major consideration e.g., propulsion of rockets and space crafts. It is also used as a reactant in alkaline fuel cell power plants on board U.S and French spaceships.

The concept of using hydrogen as a fuel for internal combustion engines is rather old. We shall make an attempt below to examine the basic issues involved and then briefly outline the historical development trend on the basis of available literature research (1,3,7, 8, 9, 10). The earliest attempt to use hydrogen for motive power was reported by the Rev. W. Cecil in 1820 and Ricardo and Burstall made further advancement in this area. But it was Rudolf Errens who tested the hydrogen-air and hydrogen-oxygen fuels in piston engines extensively in 1920s. The development of air ships (the German Zeppelin Company in 1927 and thereafter the Royal Airship Works in Great Britain in 1935) first utilized hydrogen, which was normally vented for increasing the lift, to fuel internal combustion engine along with other liquid and gaseous fuels. The vehicles, over 1,000 in number, were converted to hydrogen and hydrogen/petrol fuels in England and Germany in early 1930s which was revived during World War II due to the shortage of oil. The interest on hydrogen as an automotive fuel was renewed once again in 1970s. The land-based transportation powered by internal combustion (I.C) engines such as automobiles, buses and trucks as well as air planes were considered as the main targets for automotive use of hydrogen this time.

Among these two modes of transportation, jet aircrafts were suggested for the first major use of liquid hydrogen as a fuel since it has the advantage of being 2.5 times lighter than the conventional jet fuel. Hydrogen, however, occupies 3 times the volume of jet fuel which, by no means, is a limited factor in this case. Thus liquid hydrogen has not only excellent weight advantage but also less serious nature of the boil-off loss and distributional problem for use in jet aircrafts. "It has been estimated that the use of liquid hydrogen can increase the range of a Mach 3 supersonic aircraft by 30 percent over that of a jet-fuelled aircraft. The use of liquid hydrogen also gives the designer a good sink to cool the engine and structural parts of hypersonic aircraft. As early as 1957, liquid hydrogen was successfully used to fuel a B-57 aircraft at Mach 0.7 by the National Aeronautics and Space Agency's Lewis Research Centre. As an interim measure, pollution at take-off and landing could be alleviated by using relatively small wing-tip liquid hydrogen tanks (1).

The Lockheed Corporation, National Aeronautics and Space Administration (NASA) and Boeing have reportedly examined the potential application of liquid hydrogen to conventional aircrafts at one time or another (10). The former Soviet Union has also successfully experimented with liquid hydrogen in its Tupolev TU 154 since 1988. Messerschnitt - Boelkow-Blohm (MBB), the German partner in the Airbus Consortium, has also announced its intention to develop hydrogen fuelled Airbus A 340 which is expected to come in service from 1998. At the 1990 Hannover Air Show, the Soviet Union and Germany have announced to jointly develop commercial aircrafts based on liquid hydrogen (17). There are also plans to develop national aerospace planes in USA, Britain, Germany and Japan which may have speeds of 5 to 25 Mach and utilize hydrogen as a fuel (3). It is expected that subsonic, supersonic and hypersonic passenger jets will be flying on hydrogen early in the next century.

The major research on automotive use of hydrogen, however, is concentrated on land-based vehicles. The advantage of hydrogen as an engine fuel which can be used without extensive re-equipment as well as its potential impact on electrical power industry has made it an active area of research in recent years. The availability of hydrogen for experimentation due to its tonnage production has also facilitated the research. The main objectives of these research projects are to check the air pollution and find a practical substitute to conventional oil products in the long run.

While most of the current research works appear to be directed towards the adaptation of existing I.C. engines, others have attempted to develop new concepts for use of hydrogen as an engine fuel. These research efforts are basically concentrated in two areas: a) engine development; and b) hydrogen storage. We shall first of all clarify the main issues involved in engine development and hydrogen storage before examining the international development trend in automotive use of hydrogen.

The early results of the automobiles converted to run on hydrogen fuel were very much encouraging. These modified IC engines were characterised by increased efficiency and they practically yielded little pollution. But there were many problems associated with engine operation. The engines designed specifically for hydrogen fuel were, therefore, expected to be more efficient and pollution-free than the modified engines. This opinion was corroborated by the fact that the peak efficiencies of some of the existing internal and external combustion engines operating on cycles other than Otto cycle are significantly higher than that of the conventional petrol/piston engine. This is evident from the typical thermal efficiencies of some of the propulsion systems shown in Table 4. Hence the engines having higher thermal performances than standard IC engine could be adopted for hydrogen fuel even though they may be heavier and bulkier than the later.

TABLE 4

Thermal Efficiencies of Power Systems

Propulsion System	Efficiency (%)
1. Petrol / Piston (Otto)	22 - 32
2. Petrol / Rotary	18 - 30
3. Diesel	35 - 38
4. Gas Turbine (Regenerative)	20 - 30
5. Stirling	29 - 40

Source : Shepard et al: "Introduction to Energy Technologies" (6).

The next interesting feature is the scope of using hydrogen in gaseous, liquid and hydride forms as an automotive fuel. The form in which hydrogen will be used an automotive fuel has important implications on its economy, storage as well as safety. As hydrogen is generated in gaseous form, a change from its gaseous form to liquid or hydride form would involve significant efficiency losses. Hence the simplest and most economic approach is to use hydrogen as an automotive fuel in gaseous form. But the gaseous hydrogen imposes severe technical limitations for storage and safety in comparison to liquid and hydride forms.

The hydrogen storage options in a vehicle together with their implications in terms of relative storage weights and volumes are illustrated in Table 5. The estimated weights and volumes for each storage option expressed in the table are relative to the same energy content of petrol.

TABLE 5

Hydrogen Storage Options

Hydrogen Storage System	Relative System Weight [1/3]	Relative Contained Volume [1/3]
1. Gas (at 136 atm or 2000 psi)	15.0	24.5
2. Liquid (at 37° R)	2.4	3.8
3. Solid (Metal hydride)[2]	4.6	4

Notes : [1] Relative to petrol, as unity for same energy content.
[2] Magnesium hydride, 40% porosity
[3] Relative weight includes that of containers

Source : Considine D.M. (Editor) ; Energy Technology Handbook (1).

It is evident from Table - 5 that a compressed gas system has a big disadvantage in storage since it requires 15 times more relative system weight and 24.5 times relative contained volume than petrol for the same energy content. Even though the hydrogen-fuelled vehicles will have greater efficiency than petrol engines in terms of distance covered per unit energy at the same cruising speed, the use of gaseous hydrogen will severely limit the range of such vehicles or frequent refuelling will be essential.

Liquid hydrogen offers the most compact solution among the three hydrogen storage alternatives. It has only 2.4 times more relative system weight and 3.8 times more relative contained volume than petrol for the same energy content. But since liquid hydrogen boils at 20 K, it requires a large dewar with excellent thermal insulation. It has been reported that the containers capable of withstanding 30 Gs are presently available which can be used to overcome the burst upon collision for liquid hydrogen storage (5).

Magnesium hydride is at a 4.6 weight disadvantage and would require 4 times the tankage in comparison to the same energy content of petrol. It is also at disadvantage in comparison to liquid hydrogen 1.92 times weightwise and 1.05 times volumewise. Thus the hydride form would add additional weight and volume to the vehicle than liquid hydrogen.

The relative safety of petrol and hydrogen is another important issue for use in passenger vehicles. For this purpose, the important properties related to safety parameters for petrol and hydrogen are presented in Table 6 which show that hydrogen is a more hazardous material than petrol. It is apparent that most of the properties such as quenching distance, combustion range and flame velocity are much higher for hydrogen than petrol. While hydrogen requires much higher temperature to ignite, the energy required to ignite it is much lower than in case of petrol so that these two properties tend to balance each other.

TABLE 6

Comparision of Safety Parameters for Hydrogen and Petrol

Property		Hydrogen	Petrol
1. Ignition Energy	(Kcal) (J)	4.79×10^{-7} 2×10^{-4}	5.95×10^{-6} 2.49×10^{-2}
2. Quenching Distance	(cm) (in)	0.061 0.024	0.249 0.098
3. Ignition Temprature	(°K)	1085	495
4. Combustion Range	(%)	4 - 75	1.5 - 7.6
5. Flame Velocity	(Cm/sec) (in/sec)	269.24 106	30.48 12

Source : Shepard M.L. et. al; Introduction to Energy Technology (6).

From the safety viewpoint, both gaseous and liquid hydrogen are more hazardous than petrol or metallic hydrides. While gaseous hydrogen has very wide flammability and detonability limits, the boil-off problem is inherent in cryogenic storage systems. Hence metallic hydride is the safest form for hydrogen storage than either petrol or uncombined hydrogen. Hence the following conclusion can be drawn regarding the use of hydrogen in vehicles.

a) Gaseous Hydrogen: It is an excellent automotive fuel. But it imposes heavy penalty in terms of storage weight as well as volume. It is also hazardous to handle and store in this form.

b) Liquid Hydrogen: It is technically the best alternative (both storage weightwise and volumewise) for motive power supply to vehicles operating both normal and short haulage. But it is rather an expensive option due to the need for cryogenic storage. The cryogenic technology has considerably advanced in recent years and superinsulated vacuum dewars with the loss rate of only 0.5 to 2 percent per day for different capacity range are available in the market for storage and transportation of liquid hydrogen. The boil-off problem, however, remains for safety of handling and storage.

c) Metal Hydrogen: From the storage viewpoint, metal hydrides offer the second best solution for automotive use of hydrogen. It has weight disadvantage to liquid hydrogen almost by a factor of 2. It is also relatively expensive. But it is the safest option among all alternatives.

The safety issue has often been exaggerated out of proportion. Hydrogen is certainly a hazardous material and it should be handled with due caution. But under normal circumstances, hydrogen may not be more hazardous than other conventional fuels. Besides, appropriate sensors have been developed today which can detect hydrogen in concentration as low as 0.1 percent hydrogen/air mixture (17). These sensors can activate alarm system and shut off hydrogen supply.

Now we shall examine the broad international R&D trend in automotive use of hydrogen. The early research works had shown that hydrogen combustion in I.C engine is associated with some undesirable results such as pre-ignition, backfire, knocking and rapid rate of pressure rise during combustion. Various methods of fuel induction techniques together with other appropriate measures were, therefore, investigated by different researchers to solve these problems. Some of the major experimentation undertaken for this purpose include, among others, the followings:

a) Use of hydrogen rich mixture of hydrogen and oxygen (Perris, California Smogless Automobile Association, 1971);

b) High pressure injection of hydrogen (Murray and Schoeppel, Okhlama State University, USA);

c) Exhaust Gas Recirculation (EGR) technique (University of California at Los Angeles (UCLA) and Brigham University);

d) Hydrogen Induction Technique (HIT) with gaseous hydrogen at normal pressure (University of Miami);

e) Injection of water into cylinder (Wallace; Watson and Milkins; Peschka and Nieratschker);

f) Injection of cooled exhaust gases into cylinder (Buchner);

g) Use of cold gaseous hydrogen (Peschka and Nieratschker);

h) Late Injection Rapid Ignition and Mixing (LIRIM) scheme (Honan);

i) Injection of gaseous or liquid hydrogen late in compression stroke (Furuhama and Kobayashi; Swain et. al; Peschka, Varde and Frame);

j) Use of lean-burn carburator (Bindon et. al);

k) Use of special oils and materials (Watson et. al);

l) Increase in compression ratio (Watson et. al; Jingding et. al);

m) Use of mixture of hydrogen, oxygen and argon (De Boer and Hulet);

n) Cryogenic aspect of hydrogen fuelling for automotive application (DFVLR, Germany);

o) Detailed investigation on hydrogen engine (University of Miami for Department of Energy, USA);

p) Hydrogen operated vehicles (Daimler Benz, Germany);

q) Rankine cycle engine for utilization of liquid hydrogen car fuel as a low temperature source (Furuhama et. al., Musashi Institute of Technology, Japan);

r) Time Manifold Injection (TMI) system (Das and Mathur, IIT, Delhi); etc

Besides neat hydrogen operation, research have also been undertaken for hydrogen petrol hybrid operation which have also produced encouraging results e.g., increase in brake thermal efficiency, reduction in specific fuel consumption and low yield of CO and NO_x emissions.

A lot of present hydrogen research works on automotive use are concentrated on spark-ignited (S.I) engines. But these engines cannot supply large output power as diesel engines. As compression ignition (C.I) of hydrogen-air mixture is extremely difficult, comparatively less research have been undertaken on diesel engines. But lately research works have began in this area as well. Again, the present research can be divided into hydrogen diesel dual operation or neat hydrogen fuel. In this respect, the automotive engines now under development, particularly the S.I. direct - injection (D.I) engine is expected to substitute diesel engines efficiently.

Daimler Benz (Mercedes) of Germany is also working in this area for almost two decades and has introduced a fleet of hydrogen fuelled automobiles with metallic hydride storage system for test runs in Berlin and Stuttgart which include mixed fuel (hydrogen/petrol) passenger cars and delivery vans for hydrogen operation. These fleets of Mercedes are reported to have extremely safe and reliable operation since 1974 under varying operating conditions.

The German Aerospace Research Centre (DLR) in collaboration with BMW, another well-known German automobile manufacturer, are also experimenting with liquid hydrogen fuelled vehicles for a long time. They have experimented adopting different techniques; first vehicle with time intake port injection (TIPI), water injection and exhaust gas turbocharging; and the second vehicle on the bias of cryogenic technology (specially designed liquid hydrogen pump and injectors for fuel supply with electronic control). The earlier experiment was on BMW 520 model in 1978/79 and the latest on BMW 745 in 1986.

The Ministry of Research and Technology (BMFT) in Germany is also supporting a very large scale programme for hydrogen storage device which has already established the technical feasibility of this system for practical application in vehicles with high safety standards (11).

The WELGAS project in Sweden and Germany, which generated hydrogen from wind electricity for application in domestic and automotive uses, ran successfully in both countries before it was stopped in both countries due to cost reasons. But a serious reexamination of social costs of pollution is meanwhile taking place in Europe, particularly in Sweden. Research works are also undergoing to produce a hydrogen engine which will combine all desirable properties required for an automobile e.g., high efficiency, low fuel consumption, minimum level of pollutant emission and a high degree of safety and reliability. Hydrogen powered vehicles have been built and tested in many countries over the years. An attempt has been made in Table 7 to compile a summary of these developments during the past two decades from various sources.

The passenger car has been one of the main area of focus for automotive use of hydrogen in advanced countries. In this respect, the penalty imposed by hydrogen fuel for accommodating a larger storage volume and weight than in case of conventional petrol engine is, under normal circumstances, likely to limit the vehicle range[5] as well as restrict the freedom in design so that the hydrogen-fuelled cars may not be competitive with petro/diesel engine cars in the market. The present development of hydrogen cars, however, have considerably alleviated these apprehensions. Automobile manufacturing is one of the most competitive business in the world where the multinational companies are competing each other with the introduction of several new models of their cars each year so as to acquire a larger share of the market for themselves. As consumers'sovereignity rules supreme in the market, the hydrogen-fuelled car with distinct storage disadvantage may still be considered as a risky proposition. In reality, the hydrogen-fuelled cars are likely to be costly both in terms of their initial cost as well as operating cost (higher cost of hydrogen than petrol or diesel) under the present condition. Hence the large-scale development and use of hydrogen-fuelled cars may need special incentive such as heavy taxation on fossil fuels, or even special pollution control legislations as in the case of the State of California, USA.

The present international development in battery-powered electric vehicle indicate that it could possibly offer competition to hydrogen as a transport fuel in future. It is, therefore, worthwhile to compare battery-powered vehicles with hydrogen-fuelled vehicles. The battery powered vehicles require heavy batteries which have to be stored in the vehicles. So they impose penalty on vehicles as in case of hydrogen storage. The capacity of the batteries can be reduced like hydrogen storage can by curtailing the vehicle range, but that would necessitate frequent recharging of batteries. In this context, there is a major difference between battery storage and hydrogen storage. While hydrogen can be filled up immediately as required in a service station (or the entire storage tank can be quickly replaced), this is not the case with batteries. Recharging of batteries is not a problem at all (it will only require a large number of power outlets at vehicle parking areas), but it takes considerable time. As a result, there is an upper limit on the proportion of time a battery-powered vehicle can be driven, and on how long it can be driven without charging. These limits are clearly unacceptable in many transport operations such as interurban buses and trucks, trains, ships, aircrafts, etc. So hydrogen may be used to power large and long-haul vehicles even if battery powered vehicles will be commercially successful for small and short-haul vehicle operations. Hence hydrogen, though more expensive than electricity in terms of delivered energy, may still command a significant portion of the market for transport energy in future.

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5 For example, a standard vehicle in U.S condition has 20 US gallons storage tank

TABLE 7

Development of Hydrogen Fuelled Vehicles

Year	Producer	Model	Hydrogen use
1970	Oklahoma State University		Gas
1971	Perris Smogless Automobile Association	Ford F 250 Truck	Liquid
1973	Billings Energy Corporation	Ford Monte Carlo	Liquid
1973/74	Los Alamos National Laboratory (LANL)	1.5 ton Pick-up truck	"
1973/74	University of California at Los Angeles	AMC - Jeep	"
	University of Miami (First conversion)	1971 Model 1600 Toyota Corolla	Gas
	(Second Conversion)	Pontiac 196 m^3 4 cylinder	.
1974	Daimler Benz (Mercedes)	a) Passenger car (Mixed fuel)	Hydride
		b) Delivery van (Hydrogen)	Hydride
1975	Musashi Institute of Technology, Japan	Datsun E 210 Musashi III	Liquid
1978/79	DFVLR and University of Stuttgart, FKFS	BMW 520	"
1979	LANL/DFVLR Joint Car Project	Buick Century	"
1980	Musashi Institute of Technology, Japan	Musashi IV	"
1981	DFVLR - Stuttgart	BMW 520	"
1982	Musashi Institute of Technology, Japan	Musashi V	"
1984	BMW - DFVLR	BMW 735 1	"
1984	Musashi Institute of Technology, Japan	Musashi VI	"
1985	Welgas - Hydrogen Car	Saab 900	Hydride
1988	Fachhochschule, Weisbaden	Opel	
1990	Zollbruck, Switzerland	Toyota Hiace Combi	Hydride
1990	Solar-Wasserstoff-Bayern (SWB) Ford Fiesta (25 Series production)	BMW	(3 fuel system) Liquid Hydride and Fuel Cell

Source : The Hydrogen Organisation (12); Considine (1); Tegstrom O. (13).

4.2 Domestic Use

Now we shall turn to the use of hydrogen as a domestic fuel. Hydrogen is an excellent domestic fuel as evidenced by its properties earlier. In fact, it was used practically in all large cities of Europe and USA in form of city gas with hydrogen content between 50 to 60 percent from of 1850 onwards and substituted with natural gas only in early part of this century. As hydrogen is considered in Nepal for cooking and lighting in domestic sector, we shall examine its scope of application together with the current international development trend below.

Hydrogen has a major advantage as a direct heating or lighting fuel in domestic sector. It burns with faster, hotter flame than natural gas and its mixture with air is also flammable over a wide range of compositions. The combustion of hydrogen also does not yield any noxious or hazardous substances. Given these properties, hydrogen can be used as a domestic cooking, space heating and household lighting fuel.

The use of hydrogen in cooking operation would require design modifications on existing gas cookers. There are various types of gas cookers in the market. While an ordinary gas cooker or stove has a burner efficiency of about 50 percent, better gas stoves having an efficiency of 70 percent and low NO_x emissions have already been developed[6]. The modification of these cookers for hydrogen fuel should take into account several factors such as hotter flame of hydrogen than natural gas or LPG, energy content of hydrogen fuel (largest energy per unit mass and lowest per unit volume), etc. The design modifications can be undertaken with necessary adoptive research. In fact, similar conversion of burners, heating systems and appliances were made earlier in U.S.A and Europe when they switched from manufactured gas (city gas with about 50 to 60 percent hydrogen) to natural gas in early part of this century. The domestic appliances using hydrogen as a fuel has a major advantage since they need not be vented (except where water vapour and resulting humidity may be objectionable) due to the lack of any noxious by-products or substances of hydrogen combustion.

The use of hydrogen in space heating would also eliminate or simplify the design of household chimneys for the same reason. Further, the low ignition energy of hydrogen (2×10^{-4}J) enables low temperature catalytic burning. It is used in the concept of catalytic "flameless" central heating system which virtually eliminates the production of NO_x by maintaining the temperature of a catalytic bed as low as 100°C.

Hydrogen can also be used for household lighting purpose in various ways; as a gas directly or through the generation of electricity via fuel cells or by condoluminescence process. The lighting appliance in condoluminescence, which is a cold process, is reportedly similar to the conventional fluorescent lamp in which phosphorous is spread on the inside of the tube. When a small amount of hydrogen comes into contact with the phosphorous, it combines with the oxygen present in the air to excite bright luminescence in the phosphorous (1).

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6 This efficiency refers to flame burners, catalytic hydrogen burners have much higher efficiency than flame burners.

Prototype catalytic space heaters and water heaters fuelled with hydrogen have already been constructed in Japan, USA and Europe. The lifecycle cost comparison shows that hydrogen offers distinct advantage in terms of energy efficiency and capital equipment requirements that can be readily exploited if energy-efficient end-use technologies are adopted.

Various types of domestic appliances required for hydrogen application have also been developed. In this context, the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany has been researching on new catalysts and systems development for hydrogen-based domestic appliances since many years. The main emphasis of research has been on the development of 3 types of catalysts. Meanwhile, this institute has already designed, tested and delivered catalytic cooker (1Kw), water heater (4 kw), space heating system (6Kw), absorption refrigerator with catalytic hydrogen air burner and hydrogen street lamp or gas lamp (14,15,16).

It is interesting to note here that the first "hydrogen house" in Europe was constructed at Zollbruck in Switzerland by Markus Friedli, a Swiss architect, who was subsidized by the Berne Canton. Hydrogen is obtained by electrolysis from solar cells installed on the roof of the building and stored in a hydride vessel. It supplies all the domestic energy needs including cooking (specially designed combustion device for cooking range), space heating (4 Kw) and washing machine. Rooms containing hydrogen equipment in this house are outfitted with two-stage censors, detecting concentrations as low as 0.1 percent hydrogen/air mixtures which activate alarm signals and shut off the main hydrogen gas pipe (17). Similarly, the Fachhochschule Wiesbaden project utilizes hydrogen generated from wind electricity for cooking, space heating (4-6 Kw), gas lamps, motor generator (8.5 KVA) and fuel cell (2 Kw) operation (13). Hydrogen generated from solar cells is also experimented in Bolkow-Stiftung at Ottobrunn, Germany for cooking and space heating (4-40 Kw) (13). Finally, the solar Wasserstoff - Bayern is also experimenting with hydrogen obtained from solar cells in space heating and fuel cell (86 Kw) operations (13).

4.3 Other Developments

The current international development trends in the R&D of hydrogen in automotive and domestic uses were discussed above. Besides these trends, it is also necessary to note here other developments related to the use of hydrogen as a fuel in the international scene. The first type of development pertains to the hydrogen production technologies. Among the various methods of hydrogen production from water, electrolysis is the only process which is widely used in industrial application. While the early industrial electrolyzers operated at 60 to 70 percent efficiencies. In theory, electrolyzers can approach a maximum electrical efficiency of nearly 120 percent as the result of the ideal unit absorbing ambient heat and also converting this energy into hydrogen. A reasonable, practical target for an improved electrolyzer appears to be around 100 percent (1). Hence research efforts are aimed today towards new advanced concepts in electrode design and material improvement so as to reduce cost, increase reliability and extend the useful-life of electrolyzers. The experimental results with advanced alkaline electrolyzers in combination with Photo Voltaic electricity have already indicated very low specific energy consumption (18).

Besides the conventional electrolysis process, considerable research works are being undertaken to develop new processes such as direct thermal decomposition or thermolysis, thermochemical processes and photolysis. The thermolysis process uses high temperature (>2500° F) and low pressures to split water into its basic components. The research is at present directed towards the development of economic techniques for cooling the containers

and separating the gases, which otherwise recombine after cooling down. On the other hand, water can be splitted at much lower temperature than its normal decomposition temperature by using an intermediary metal or chemical. The maximum temperature required to affect decomposition in this case is 730°C which is lower than nuclear-reactor-coolant temperature (850°C) in a high-temperature gas-cooled reactor (HTGR). Hence various thermochemical cycles are being investigated in many countries, among which, the prominent are: Nuclear Research Centre, Julich, Germany; General Atomic Co., San Diego, California; Institute of Gas Technology, San Jose, California; European Atomic Energy Community, Ispra, Italy; etc(1). Research works are also undergoing in the development of photolysis process which generates hydrogen and oxygen in presence of sunlight by using an electrochemical cell or through some biological systems.

It is also necessary to note here the development of new solar cell, new fuel cell and new hydrogen liquefaction process which are directly related to hydrogen production or conversion technologies. Novel photo voltaic cells are being now researched where the thin layers of different cells are expected to increase the conversion efficiency to 35 percent (3). In this respect, the new solar cell developed by M. Graetzel replaces silicon by titanium dioxide and thereby enables the price reduction by a factor of 50. The new cells would be in the market by 1992 and they are expected to generate electricity at 3 cents/kwh (13). At the same time, Billings Energy Corporation is introducing new fuel cells (called lazercel) for small cars at Independence, USA (12). "Since fuel cells and electromotors are about two times as efficient as internal combustion engines, hydrogen storage requirements as well as fuel costs per unit distance travelled are reduced. Another advantage of the Billings Lasercel is its ability to operate in reverse i.e., as an electrolyzer, which make its application possible even without a hydrogen infrastructure" (18). A new, revolutionary liquefaction process for hydrogen (called nagnetic liquefaction) is also being developed at the Los Alamos National Laboratory which may need less capital investment and less maintenance than conventional process. The circuit efficiency of this new process is 60 percent compared to 30 percent for conventional system (3).

The second type of development is concerned with new technologies for hydrogen utilization. Steam generation by controlled burning of hydrogen and oxygen is such a new process. The development of this new generator (called Hydronic) has enabled us to produce highly pure, saturated or superheated steam within a matter of seconds for industrial as well as power generation (19,20). It has been test operated at Lampenholdsheim, Germany for 100 MW electric power station since 1986 (12).

The German-Saudi Arabian HYSOLAR (Solar hydrogen energy) project is another type of development which was started in 1985/86. This project has multiple objectives: a) operation of a 350 KW-system called Riyadh Solar Village; b) 10 KW test and research facility at Stuttgart and 2 KW test and research facility at Jeddah; c) fundamental research programme; d) system studies e) utilization programme, etc (21). The HYSOLAR test facilities offer today's most versatile test capabilities for photovoltaic powered electrolysis covering a wide range of areas. The research programme intends to investigate new fundamental principles and to improve the efficiency of existing technologies for solar hydrogen production. The system studies will determine the conditions critical for solar hydrogen development as well as for system optimization. Finally, the utilization programme includes a number of classic and advanced hydrogen technologies. In the starting phase, the following technologies will be assessed within the framework of this project: a) H_2-fuelled internal combustion engine: b) H_2-catalytic combustion heater: c) Modified H_2 - gas lamps: d) H_2/O_2 steam generator; e) H_2-fuelled thermoelectric generator: f) H_2-fuelled refrigerator. International industries and manufacturers both in Germany and

Saudi Arabia are expected to participate in a comprehensive development programme in the next stages of hydrogen utilization research in the HYSOLAR project. Thus the HYSOLAR project is an excellent example of cooperation between the advanced and developing country for long-term evolution of solar energy systems.

Finally, we shall outline the Euro-Quebec Hydro-Hydrogen Pilot Project (EQHHPP) here, which if feasible, could be a milestone for large-scale application of hydrogen as a fuel at the international level. This pilot project intends to demonstrate the feasibility of Quebec's hydropower conversion into hydrogen for use in European market on the basis of a 100 MW hydropower plant (22). The clean and renewable primary energy in the form of Quebec hydropower will be converted into hydrogen via electrolysis which will be then transported by sea either as liquid hydrogen or methylcyclohexane (MCH) to European port of Hamburg where it will be stored. This hydrogen is proposed to be used in different ways: a) vehicle application (hydrogen bus fleet); b) airplane application (liquid hydrogen in Airbus Pilot Plane); c) utility application electricity/heat cogeneration; d) natural gas for use in industry and households); and e) space application (spacecraft technology). This project was initiated in early 1989 by the Commission of the European Communities and the Quebec Government with European and Canadian industrial partners and research institutions. A joint management group for the execution of the feasibility study was formed which is headed by the Ludwig-Bolkow Foundation on the European side and Hydro-Quebec on the Canadian side. The present study phase was estimated to last until early 1991. Blueprint production and hardware realization are expected to take 1-2 years and 3-4 years respectively.

Thus the present international trend in R&D of hydrogen related technologies amply indicates that hydrogen can be realistically considered as an energy alternative. The required technological capabilities for this purpose already exist in industrialized countries. The safety problems also appear to be satisfactorily solved for automotive and domestic applications in industrial countries.

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III. NEPAL COUNTRY STUDY

HYDROGEN ECONOMY: NEPALESE PERSPECTIVE

Rana, Krishna, et. al.

1. Comparison of Global and Nepalese Perspective

The global concept of Hydrogen Economy as discussed in Rana et al., Hydrogen Economy can hardly be advocated for application at this stage in a resource poor, developing country like Nepal which has also very limited scientific and technological capabilities. Nevertheless, given the peculiar energy demand and supply situation prevailing in Nepal, hydrogen can be advocated as an energy alternative strictly on pragmatic basis for selective applications with immediate effect. It is so because hydrogen has extremely high relevance as an energy source in Nepalese context even at this stage due to the following conditions :

a) Overwhelming dependence of Nepalese energy sector on traditional biomass which has triggered the ecological crisis;

b) Poor fossil fuel reserves in the country;

c) Balance of payments problem for import of fossil fuels to Nepal;

d) Difficult access to sea due to land-locked position of Nepal;

e) High cost of overland transportation and distribution in rugged mountainous terrains;

f) High potential for hydroelectricity generation in Nepal; and

g) Existence of surplus hydroelectricity in the power systems which is virtually wasted.

These specific conditions compel Nepal to examine the hydrogen option as an energy alternative before the real advent of hydrogen economy at the global level.

The concept of hydrogen as an energy alternative has thus emerged in Nepal from the critical energy situation in the country. It seeks to examine the state-of-the-art in hydrogen related technologies available today in the global market in order to selectively utilize them for averting the impending ecological catastrophe in the country. Hence the Nepalese concept of hydrogen economy does not herald the advent of real hydrogen economy as envisaged in the global concept and it can be considered only as a humble step towards the ultimate objective. Further, the global "hydrogen economy" and its miniature Nepalese version entirely differ in their basic concepts, the only common thing in both versions being the use of hydrogen as an energy alternative and that too with a difference. Let us examine these differences at some length below which are also summarized in Table 1.

The first major difference between the global and Nepalese concepts lies in the specified role for hydrogen. While hydrogen is conceived as an universal energy form for transmission, storage, delivery and application in the global concept, the Nepalese version dispenses with most of these roles altogether. Hydrogen is considered in Nepalese concept simply as an energy source like any other sources without ascribing it any universal role.

The second major difference between the global and Nepalese concepts lies in the technology of hydrogen production. The global concept is based under a scenario of significant technological breakthroughs for hydrogen production from water while the Nepalese concept is envisaged under the existing state-of-the-art in electrolysis technology. Again, the global concept is applicable when the world's fossil fuel reserves will be exhausted in a distant future whereas the Nepalese concept is applicable under the present energy demand and supply conditions in Nepal. Further, the global concept intends to tap the solar or nuclear energy sources for large-scale hydrogen production in future whereas the Nepalese version attempts to harness the available surplus or waste energy in the existing electric grid for hydrogen production in small scale.

Table 1

TABLE 1

Global and Nepalese Concept of Hydrogen Economy

ISSUES	GLOBAL CONCEPT	NEPALESE CONCEPT
1. General Concept	Hydrogen as the universal energy from the transmission storage, delivery and application	Hydrogen as an energy alternative under the existing demand and supply conditions in Nepal.
2. Hydrogen Production	New technologies envisaged. Technological breakthroughs essential.	Conventional electrolysis proposed
Scale of Operation	Large Scale	Small Scale
3. Power Source	Solar or nuclear (large scale)	Surplus electricity available in the grid (small scale)
4. Hydrogen Transport-ation	Underground pipelines.	No transportation envisaged. Local consumption.
5. Hydrogen Storage	Underground reservoir / overground tanks.	Small tanks and cylinders.
6. Hydrogen Application	Direct application or conversion to electricity for end-use.	Direct application only.

The Nepalese version thus essentially intends to utilise the surplus electricity in the form of hydrogen so that the total quantity of production will be relatively small. In fact, the quantity of hydrogen production will change from time to time depending upon the availability of surplus energy in the grid. Hence, unlike in global concept, hydrogen is not likely to figure as the dominant form of energy. On the contrary, it will have only a small share in the overall energy supply in Nepal

The next major differences between the global and Nepalese concepts lie in hydrogen transportation, storage and application. While underground pipelines, underground reservoirs and overhead liquid hydrogen storage tanks are the integral components of the global hydrogen concept, the Nepalese version proposes to consume the small quantity of hydrogen produced from surplus hydroelectricity locally without involving any transportation and steel tanks as well as cylinders may be used for storage of gaseous hydrogen. Finally, hydrogen is conceived in Nepalese version simply as an energy alternative which will be preferably used directly without any change in form, unlike in global concept where hydrogen may be used directly or converted into electricity again for end-use applications.

The Nepalese concept of hydrogen as an energy alternative is thus devoid of any grandiose vision. It is just a pragmatic approach to establish hydrogen as an energy alternative under the existing technological and market conditions in Nepal. Hence an attempt is made in the next chapter to examine the hydrogen scenario in Nepalese energy perspective.

2. Hydrogen Scenario in Nepalese Energy Perspective

2.1 An Overview of Energy Sector : Energy "Crisis" in Nepal

The traditional energy such as firewood, agricultural wastes and animal dung predominates the present energy consumption pattern in Nepal (Table 2). In fact, firewood represents the main source of energy supply followed by agricultural wastes and animal dung. The contribution of commercial energy (petroleum products, coal and electricity) in overall energy supply remains very low. While oil and coal, both import articles,dominate this category, the share of indigenous hydroelectricity remains virtually negligible. In terms of total energy consumption, the traditional fuels together accounted for as much as 94.76 percent in 1990-91 whereas the share of commercial fuels was only about 5.3 percent in the same year (Table 2 and Figure 1.)

The forest resource has been exploited as the principal source of fuel in Nepal since time immemorial. But the rapid growth of population in past few decades has not only led to the expansion of farmland at the expense of virgin forest land but also increased the consumption of firewood and timber proportionately. In addition, the overgrazing of forest by the large cattle population has further aggravated the situation.

Nepal has an estimated 6.73 million hectares of forest and shrub land, out of which about 50 percent area (3.34 million hectares) is accessible to the rural population for firewood collection. The estimated consumption of firewood in 1990-91 was 11.99 million tonnes whereas the sustainable annual yield of firewood from accessible forests was only a meagre 6 million tonnes (1) which clearly indicates the magnitude of deficit for sustainable supply. It has been reported that firewood consumption has been declining in densely populated lower Terai plains due to its scarcity and now comprises less than 50 percent of the total household energy use. The share of firewood in the hills and mountains, however, continues to remain above 90 percent (2).

TABLE 2
Sectoral Energy Demand 1990/91

(000GJ)

Sector	Fuelwood	Agr. Residue	Animal Dung	Others	Total Non Commercial	Petroleum Fuels	Coal & Coke	Electricity	Total Commercial	Total Energy
1. Domestic	195685.08 (77.9)	28821.49 (11.47)	22312.30 (8.88)	367.34 (0.15)	247186.21 (98.4)	3069.75 (1.22)		937.30 (0.37)	4007.05 (1.6)	251193.26 (93 48)
2. Industrial	4024.30 (40.99)	2452.72 (24.98)		220.66 (2.25)	6697.67 (68.22)	901.15 (9.1)	1466.70 (14.94)	752.00 (7.66)	3119.86 (31.78)	9017.53 (3 65)
3. Commercial	587.06 (29.57)				587.06 (29.57)	916.12 (46.15)	186.93 (9.42)	294.88 (14.86)	1397.92 (70.43)	1984.98 (0.74)
4. Transport						4581.23 (98.88)	45.36 (0.98)	6.73 (0.15)	4633.32 (100.00)	4633.32 (1.72)
5. Agriculture						941.25 (95.34)		46.01 (4.66)	987.26 (100 00)	987.26 (0 37)
6. Others								(83.77) (100.00)	(83.77) (100.00)	(83.77) (0.03)
Total final consumption	200296.43	31274.21	22312.30	588.00	254470.94	10409 50	1698.99	2120.69	14229.17	268700.11
% of Total	(74.54)	(11.64)	(8.3)	(0.22)	(94.7)	(3.87)	(0.63)	(0.79)	(5.3)	(100 00)

Note : Figures within the parenthesis are percent of total sectoral energy.
Source : Sharma C.K. Bhattarai L.N; "Sectoral Energy Demand of Nepal for the Year 1990/91*(1)

ENERGY DEMAND BY FUEL TYPE 1990/91

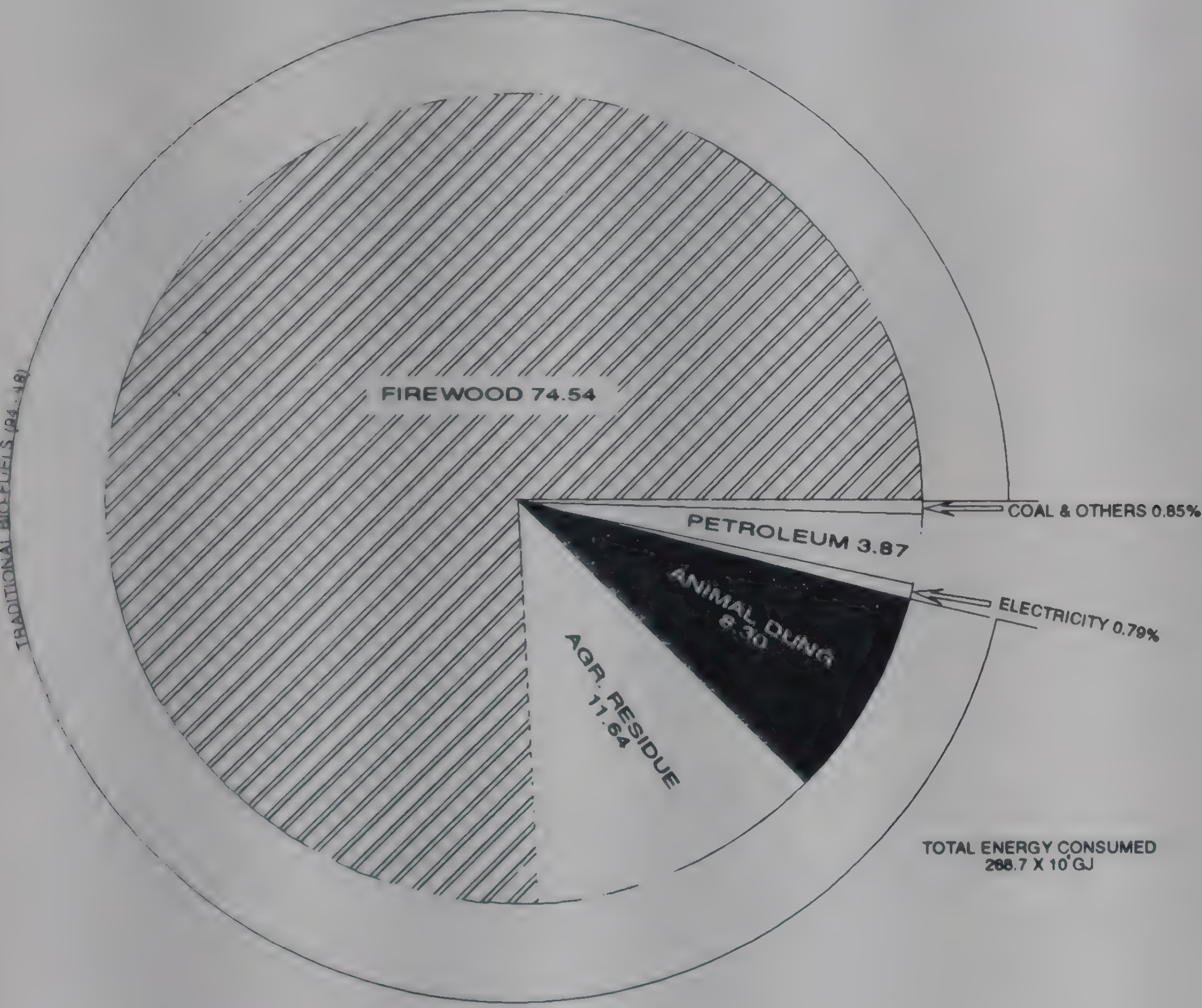

FIGURE - I

The growing scarcity of firewood over the years has gradually diverted the agricultural wastes and animal dung from the cultivated field to the household as cooking fuels with long-term detrimental impacts on soil fertility. It is estimated that in 1990-91 alone, about 2.48 million tonnes of agricultural residues (mainly rice husk and straw) and more than 2 million tonnes of animal dung were consumed as household fuels. The cumulative impact of all these facts has led to large-scale deforestation[1], soil erosion and the general degradation of environment in Nepal.

The total demand for commercial energy has been increasing over 7 per cent per annum during the 1980s which was much higher than the overall GDP growth rate during the same period. As stated earlier, the imported petroleum products and coal are the major items of consumption in this category. But the import of these fuels is constrained by the scarcity of foreign exchange. While the consumption of petroleum fuels shows steady growth trend, coal consumption remains rather static due to the constraint in coal supply from India.

The total cost of fossil fuels import is relatively high in Nepal. The outlay for import of petroleum products alone has averaged about 34 percent of Nepal's total export earnings over the 1980s (2). Side by side, the investment in energy sector has accounted a sizable proportion of total national development budget. For example, electricity infrastructure development accounted for about 17 percent of the national development expenditure during the 1980s (2). But the electrification programme has been extensive area wise rather than population wise. As a result, though 68 out of 75 district headquarters have already been electrified, the electrification programme covers today only about 9 percent of households in the country, about half of which is in Kathmandu valley alone.

On sectoral basis, domestic sector is the leading consumer in Nepal with over 93 percent share in the total energy consumption followed by organized industry and transport. In fact, cooking energy alone represents more than 75 percent of total energy consumed in domestic sector, primarily due to the use of highly inefficient traditional cooking stoves (about 10 percent efficiency). On the other hand, the organized transportation consumes about 44 percent of imported petroleum fuels and as such is the single largest sector dependent upon imported fossil fuels.

The present level of per capita energy consumption in Nepal is only about 14 GJ or 326 Kg oil equivalent (2) which is one of the lowest in the world. Nevertheless, it appears difficult to maintain even this low level of energy supply let alone go on increasing it in future. The demand for traditional energy is closely linked with population growth, but the supply has, by all means, surpassed the sustainable limit a long time ago. The poorest rural households, who have no access to alternative fuels, are suffering most from the scarcity of these traditional biofuels. On the other hand, the demand for commercial energy is also increasing very fast due to rapid urbanization and growth of non-agricultural sectors. But the scarcity of foreign exchange will not enable Nepal to increase the level of fossil fuels import substantially in future.

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1 Nepal has the highest annual rate of deforestation not only in South Asia but in the Asia and Pacific region as a whole (3).

On the supply side, Nepal hitherto has no proven, commercial deposits of fossil fuels such as coal, lignite, natural gas and oil. Apart from the depleting forest base, hydroelectricity is the only other available commercial form of energy to meet large-scale energy needs of the population. Nepal is blessed with many river systems and favourable topography for hydroelectricity generation. As a matter of fact, Nepal's theoretical hydropower potential is estimated to be about 83,000 MW out of which about 42,133 MW is likely to be economically feasible (1,2). Thus, hydroelectricity is the principal energy resource endowment of the country which accounts for as much as 78.6 percent share in the theoretical potential of indigenous energy resources in Nepal (Table 3). But despite this potential, the total installed hydroelectrical capacity of Nepal in 1992, is only 232 MW or only 0.28 percent of its theoretical potential.

TABLE 3

Theoretical Potential of Indigenous Energy Resources

Source (Type)	Annual Supply (Natural Unit)	Raw Energy Available $10^6 \times$ GJ	(%)
1. Forest (Sustainable Yield)[1_/]	17.5×10^6 MT	293.00	15.80
2. Agricultural Residue	6×10^6 MT	76.00	4.10
3. Animal Wastes	2.33×10^6 MT	25.00	1.30
4. Hydropower [2_/]	405800 Gw	1461.00	78.60
5. Direct Solar [3_/]			
- Insolation	26000 M-K	3.00	0.20
- Wind	-----	----	0.0
6. Fossil Fuels	Unknown	----	-----
TOTAL		1857.70	100.00

Notes : 1_/ Total forest yield (supply within accessible areas much smaller than figure indicated here) based on Forestry Sector Master Plan projections of sustainable supply for 2010/2011 only. Competition for land is assumed to be a limiting factor

2_/ Based on average flow.

3_/ Assumes maximum 0.0001% of land area coverage for solar infrastructure

Source: Water and Electricity Commission Secretariat (4)

Hydropower development has been envisaged in three different ways in Nepal : (a) development of micro hydropower plants in private sector for rural areas remote from the national grid; (b) development of medium scale hydropower (upto 50 MW) for national grid with private sector participation; and (c) development of large-scale multi-purpose projects at regional scale for electricity, irrigation, flood control, and navigation benefits. The large-scale multi-purpose projects are basically proposed to export hydroelectric power to neighbouring countries as a source of income generation. Some of them are indeed very large even by the world standard e.g. the Karnali (Chisapani) Multipurpose Project (10,800 MW).

Nepal is comparatively rich in non-conventional energy resources as well. The total global radiation available on landmass of Nepal is approximately 26 x 106 MW (Table 3). Wind power potential has not yet been properly assessed, but a few sites are known in the country where consistently high wind regime prevails. The potential of agricultural residue and animal dung are also fairly high (6 and 2.3 million tonnes/annum respectively) due to the production of cereal crops and existence of a large number of cattle heads in the country. Some attempts have already been made to harness these non-conventional energy resources with rice husk briquettes, biogas plants, micro hydro plants, solar water heaters, etc. But the technological breakthroughs are required to utilize these resources in mass-scale. Hence the non-conventional energy sources cannot be considered as a viable option to substitute the bulk of present energy supply in the short or medium run.

The energy sector of Nepal thus exhibits a chronic structural imbalance between demand and supply. The national energy system today relies mostly on the least plentiful domestic resources (forest and other biofuels) as well as imported fossil fuels whereas the most abundant energy resource (hydro) remains virtually unutilized. This situation basically arises due to the mismatch between the national energy supply potential (which is mostly comprised of hydro) and the national energy demand (which is mainly in the form of biofuels or heat). As a result, Nepal faces, on the one hand, massive deforestation in the hills with tragic circumstances to the Himalayan ecosystem while, on the other hand, even the limited reliance on imported hydrocarbons has choked the process of economic growth due to the scarcity of foreign exchange to import oil as well as transportation bottlenecks to distribute it in the country. Nepal thus experiences two types of energy "crisis" simultaneously; the "firewood crisis" in the nonformal sector and the "oil crisis" in the formal sector. This state of affairs demands a structural change in the pattern of energy consumption at the earliest possible time.

2.2 Sustainable Development: Role of Hydroelectricity in Structural Transformation of Energy Sector in Nepal

The desired structural change in the pattern of energy consumption in Nepal can be achieved only through a path of sustainable development i.e. the "development that meets the needs of the present without comprising the ability of future generations to meet their own needs" (5). As the bulk of biofuels consumed today in Nepal is at the cost of future generations, this broad and all encompassing concept calls for a radical change in the present energy consumption pattern without any further delay. But the proposed structural change, in whatever way it may be conceived, should fulfil the criteria which are specified below:

a) To shift the present energy consumption pattern from traditional biomass and fossil fuels to new and renewable energy sources;

b) To substitute the imported fossil fuels (petroleum products and coal) with renewable domestic sources;

c) To reduce the absolute quantity of energy required for development through change into appropriate energy forms which have higher energy density and permit higher end-use efficiency than conventional fuels;

d) To satisfy energy demand in basic needs oriented activities on priority basis;

e) To check deforestation through firewood conservation and substitution measures;

f) To conserve scarce foreign exchange used for fossil fuels import; and

g) To increase national self-reliance in energy supply.

These criteria may appear as wishful thinking and perhaps at times even mutually conflicting. But a sustainable change in the consumption pattern cannot be achieved without fulfilling them. As the energy resource base of Nepal is indeed very narrow, the above specified criteria may be fulfilled only under very special circumstances.

Needless to say, hydroelectricity is the only prominent form of renewable energy available in Nepal which can be harnessed in large-scale with existing, mature technology. In this respect, other new and renewable energy sources (solar energy, wind power, geothermal energy, etc) have also very high potential for the structural transformation of energy sector in the long run, but as mentioned earlier they cannot be considered as serious candidates at least for a decade or so due to their technological limitations. Hence hydroelectricity should play a very special role for the required transformation of energy consumption pattern either directly substituting other energy sources by itself or indirectly enabling substitution through a change in its energy form. In other words, hydroelectricity should substitute by itself or help substitute by changing its energy from the bulk of imported fossil fuels as well as the traditional firewood used for cooking operation in Nepal. Can this be really done? If so, how? This proposition may appear unrealistic, but it still deserves consideration simply because there is no other alternative available in this case.

Hydroelectricity is certainly the central element of this proposition, but it does not suggest a switch towards a fully "electric economy". On the contrary, this proposal intends to exploit the inherent problems of electricity sector or its existing inefficiency to create synergism which will enable the structural transformation in the energy sector while making the electricity sector more economically efficient at the same time.

The issues involved in this discussion are rather very complex and inter-related. Hence as a prelude, we shall examine the following aspects related to electricity generation and use at some length so as to clarify the concept of proposed synergism at the latter stage:

a) Present problems of electricity sector, particularly the availability of surplus energy;

b) Scope of direct application of surplus energy at various end-uses; and

c) Alternative measures to store the surplus energy in various energy forms.

2.2.1 Present Problems of Electricity Sector: Surplus Energy

The electric power plants are most efficient when they are operated at full-rated capacity with constant output. But this ideal condition does not prevail in real life condition since the generating rates require constant adjustment due to the wide fluctuations in daily and seasonal consumer loads. Thus in a predominantly hydro generating system, which is not properly backed by storage hydroelectric plants, the surplus energy is bound to occur, especially in wet season. This is an inherent problem of electricity sector in which a considerable amount of surplus energy cannot be used properly due to the constant need to adjust supply with demand. In addition, the electric system also experiences considerable energy losses in transmission and distribution of power. Hence the predominantly hydro-generating electricity sector comprising of mostly run-off-the river plants is characterized by considerable inefficiency. This generalization is true, even though the relative efficiency of individual system widely differs according to its technical features as well as the nature of average utility load cycle.

The Integrated Nepal Power System (INPS) is the main system in the kingdom which links eastern, central, western and mid-western regions within a single grid. This system is entirely dominated by hydroelectric plants, particularly run-of-river type of schemes where the (diesel) plants serve as standby units. The total installed capacity of this systems is 280 MW, out of which hydro comprises 232 MW and the rest 48 MW is thermal. Altogether, there are 14 hydro plants in this system with one high dam for regulation. Besides the integrated grid, there are 30 isolated local systems each one served by a small hydro in the remote regions. The installed capacity of these plants range from 32 KW to 1,000 Kw and the total capacity of these plants is 5,966 KW. The projects under construction will further add 12 MW to the INPS and 2,400 KW to the isolated local systems.

Although Nepal has very high hydroelectric power potential, the cost of power generation is relatively high in small and medium scale projects so far constructed on account of several unfavourable features such as difficult geology, high seismic sensitivity, large variations between flood flow and minimum flow in Nepalese rivers, additional transportation cost due to administrative delays have also contributed to this end. But ironically the proposed large-scale or "mega" projects, which cannot be justified solely on the basis of internal market demand, can produce electricity cheaply. These specific features of hydroelectric power generation has also inhibited the development of small and medium sized projects in Nepal. The present situation indicates that the development of storage projects will be constrained at least for a decade or two.

On the utilization side, all the existing hydroelectric systems display the symptoms of gross inefficiency as noted above. The integrated system, INPS, shows marked variations in the daily and seasonal load curves. The system peak load occurs during winter period for a few hours in the morning and evening time and the annual system load factor is around 50 percent with little variations from year to year. The isolated systems served by the small hydro system follows, more or less, the same pattern, but the annual system load factor is much lower in this case than in INPS system because the electricity is primarily used for household lighting in these areas. Needless to say, the low system load factors are synonymous to the under-utilization of installed capacity and lead to serious diseconomies or high cost of energy. They also indicate the existence of surplus power/energy in these systems especially in wet season which is normally wasted. In fact, the gross inefficiency of INPS is evidenced by the fact that as much as 28 percent of the total generated energy is lost in the system inclusive of technical losses and pilferages.

The assessment of surplus hydroenergy available in INPS has been undertaken which amply demonstrates the existence of surplus power/energy in the systems. The study on surplus power/energy available in INPS shows that the absolute size or magnitude of available surplus fluctuates over time according to demand and supply situation with deficits in certain months or years. Again, the surplus may be sometimes available throughout the year and sometimes only for some months in a year. Surplus power/energy is presently available in wet season despite the current shortage in power supply during April and May, 1992. It will also continue to be available under the given scenario up to the year 2003 A.D. despite deficits in certain years.

The nature of future hydroelectric project development will considerably affect the magnitude of surplus power/energy in INPS. In this context, several large-scale, multi-purpose storage projects with installed capacity in the order of thousand of megawatts are also proposed in Nepal, primarily for energy export to neighbouring countries. But it is yet uncertain when such projects will be undertaken, if at all. The growing environmental concerns at national, regional and global levels may create considerable opposition for construction of large storage type of projects in view of prevailing unfavourable geological and seismic features of the Himalayan region. In particular, the realisation of these mega projects may considerably depend upon the attitude of bilateral and international funding agencies due to the high dependence upon loan capital for construction purpose. Hence in all probabilities, surplus power/energy may prevail in Nepalese hydroelectric systems are likely to remain grossly inefficient even in future unless the power consumption pattern will be modified by appropriate measures.

An attempt has been made in the following sections to identify the appropriate measures for direct utilization or storage of surplus energy available in INPS.

2.2.2 Direct Application of Surplus Electricity: Potential and Limitations

Theoretically speaking, the surplus hydroelectricity can be directly used in many activities in Nepal. It could be employed as a source of motive power or heat in transport, industrial and domestic applications. But there are two important considerations for this purpose; the first pertains to the relative economic efficiency of electricity vis-a-vis other competitive energy sources and the second concerns to the frequent interruption in surplus energy availability.

Electricity is the most versatile form of energy since it could be virtually employed in all end-uses. Nevertheless, under the given state-of-the-art in technologies, the relative economics of electricity is not generally favourable in comparison to many other conventional fuels. Thus, even if electricity can be technically used in many applications, it is not necessarily economic. Electricity serves best as a motive power and light, but not as a source of heat. But this generalization does not hold true in case of transport sector where a wide variety of electric driven and oil based transport equipment are in use. As a rule, the electric driven transport equipment such as ropeways, trams, trolley buses, electric trains, and personal vehicles can compete with oil based equipment under special conditions. On the other hand, aircrafts cannot be operated at all with electric drive and other heavy vehicles such as buses and trucks are not economical with electricity. Thus under normal circumstances, electricity cannot be used to substitute liquid fuels for transport. It is also grossly uneconomical to supply process heat in majority of industrial applications. Similarly, electricity is not the most economic form of energy to supply cooking energy need. The relative economic efficiency of electricity, therefore, is not favourable in many applications. But this is not an overriding constraint in this particular case since the surplus energy, which is wasted anyway, can be utilized regardless of its end-use efficiency.

The next consideration is the off-peak or seasonal availability of surplus energy which implies that energy will not be available on assured basis for any planned activities. In addition, the surplus energy supply situation may change from day to day, month to month and year to year so that the economics of any new project based entirely on available surplus energy will certainly be in jeopardy. This is the main problem for direct utilisation of surplus energy available in INPS.

The surplus hydro-electricity has also a restricted export market in neighbouring countries, although in a mixed system it could be utilized for conserving fuel for future use. Needless to say that by the very unassured nature of its supply, surplus power cannot be considered as a continuous firm source of energy in an electrical system; it can only serve as an optional source provided that the time pattern of surplus power availability is economically compatible for substitution of other sources of energy. Hence the surplus energy may be valued at only a fraction of the prevailing tariff for electricity export (it may be at the most equivalent to the cost of coal or oil that is replaced by this surplus in thermal stations), if it can be exported at all. Hence the surplus power/energy finds no practical application today in Nepal.

The existing Power Exchange Agreement with India (up to 25 MW) certainly acts as a form of electric energy storage. The surplus of INPS is transmitted to India under this agreement which is later imported when required in Nepal. But the present agreement has a ceiling of 25 MW per annum for power exchange between the two countries. It appears, however, difficult to enlarge the scope of this agreement and practice power exchange at a large scale, particularly on the basis of available secondary energy.

The surplus hydro-energy is an inherent feature of electricity sector in Nepal as long as large-scale interconnection with the electrical systems of neighbouring country/countries will not take place and medium or large storage hydroelectric projects will not be developed. As the regional cooperation in hydroelectricity development and use will still take time, the surplus hydro-energy is likely to increase with the growth of electricity consumption in the country. Given the relative abundance of hydroelectric power potential and the lack of any other practical alternative energy supply option in Nepal, this situation is ironically absurd.

2.2.3 Storage of Surplus Hydroelectricity in Electrical Form Options & Constraints

The limitations for direct utilization of surplus electricity in INPS outlined in the foregoing section indicates that any practical solution for this problem should be in the form of creating additional seasonal load matching with the surplus availability. Since the fluctuating nature of utility load curve and the availability of surplus energy in the system is a universal phenomenon, several measures have been adopted in advanced countries to utilise low-value, off-peak energy for supplementing high-value, peak electrical energy generation capacity. The methods practised for large-scale, hydraulic energy storage are multiple dams system, pump-hydraulic storage and compressed air storage besides several other new concepts forwarded for this purpose such as magnetic storage. We shall briefly note them below.

The construction of very high dam becomes necessary for full regulation of monsoon flows due to steep, mountainous topography of Nepal, which has different technical limitations and, therefore, a large quantity of water will either have to be allowed for spilling or passed through turbines to generate power/energy on continuous basis during monsoon flood. Hence the available storage will support only a limited hydroelectricity generation for most of the year. On the other hand, if more dams will be built in cascade along the river course each one will impound a part of those flood water and release them

gradually throughout the year. In this system, the downstream plants will have enough flow spread over the year to support additional power generation. The Grand Coulee Dam on Columbia River in Washington could be cited as an example of this concept. The construction of 6 dams in Salt River Valley, Arizona, USA is another example which can store about 2,000,000 acre feet of water and about 900,000 acre feet is released in a typical year (6).

The next alternative is the pumped storage hydro scheme which came in existence in 1930s. The idea in this scheme is to pump water to the upper reservoir during the off-peak hours with the most efficient generation and then use it to provide additional capacity during the peak load periods. In other words, the pumped hydraulic storage is in essence a reversible hydroelectric station where the electric energy is temporarily converted to a hydraulic head by pumping water to an elevated reservoir. The examples of this system are Luddington and Salt River Valley in USA. The pump-hydraulic system is today the principal means of large-scale storage of electricity and it has rapidly expanded all over the world due to its numerous advantages e.g., most economic generation of peaking energy, environmental acceptability, high reliability, high flexibility, simple operation, low operating and maintenance costs, ability to utilize base load units near full load condition, etc. But the feasibility of this scheme is limited due to predominant role played by hydrogeneration and lack of thermal (coal, oil or nuclear) generation in Nepalese system. Also the capital cost of such pumped storage scheme considerably depends upon the local topography and geology.

The compressed air system (CAS) is another alternative for large-scale storage of off-peak electricity. In this system, low value, off-peak energy is used to compress air, which is later expanded to supplement high value, peaking energy generation. This system could be either constant volume (pressure tanks, mined cavern, etc) or constant pressure (above ground variable volume tanks, underground aquifer etc) facility. It essentially consists of an air compressor, an expansion turbine, a motor generator and an underground cavern or aboveground storage tank. The example of this system is 290 MW gas turbine plant at Huntorf Germany (6).

A new concept called the magnetic storage has been recently forwarded for large electric utility load levelling which is expected to be feasible, even theoretically, only in very large scale (10^7Kwh range). The principle of energy storage in its magnetic field states that in a superconducting region (close to absolute zero) a D.C current once started in a loop circuit will flow undiminished almost indefinitely until the current is intentionally diverted to an external load circuit.

All the large-scale, off-peak energy storage measures for utility load levelling noted above could in small or greater degree be relevant to Nepalese condition as well. In fact, it may be necessary to adapt one or more of these measures in future when rapid load growth will make peaking capacity more and more insufficient in INPS. But these measures cannot be considered in isolation and they must be built into overall masterplan for electricity development in the country.

The available magnitude of surplus power/energy in INPS does not, however, still justify the construction of such large-scale storage projects in Nepal. Nevertheless, these projects have long lead time and require considerable investment funds so that they must be conceived in advance, preferably at least a decade or more. The power development programme at present under consideration in Nepal does not include any such storage facility, except the facilities (pondage for daily storage) aimed at meeting the daily peak. Hence the off-peak energy storage measures, especially the seasonal off-peak surplus storage measures are not likely to figure in short-term or even mid-term scenario of power development in Nepal.

Finally, it is pertinent to examine the scope of storage batteries for electric utility load levelling in future. The storage batteries currently in use are lead-acid (most common and versatile), nickel-iron (mostly used in industrial trucks, railway cars, electric vehicles, aircrafts, emergency supplies, etc) and nickel-cadium (consumer products). Each of them has its own advantages and disadvantages. Advanced version of lead-acid and nickel iron are today considered as candidates for powering electric cars in future. Besides that, other types of batteries are also currently under development (e.g., nickel-zinc, iron-air, zinc-chlorine, lithium-metal sulphide, sodium-sulphur, zinc-bromine, lead-manganese oxide, etc) some of which could possibly offer a practical solution for electric utility load levelling in future.

Electric vehicle is today one of the major area of research and development in world-wide scale. As the batteries are the key technological component of electric vehicles, the major thrust of research and development is focused in this areas. Currently, there are three leading contenders (7): a) lead-acid batteries (General Motors, USA) due to low cost, availability and ease of recycle despite their heaviness and bulkiness; b) nickel cadium batteries (Japan Storage Batteries) due to high electric current despite their high cost, heaviness and problem of recycle; and c) sodium-sulphur batteries (Asea Brown Boveri and NGK Insulators) due to lightness, compactness and high energy densities despite their need for an auxiliary equipment for heating. Although the environmental pollution control measured particularly the recent emission-control legislation introduced by the state of California, USA is attributed as a major motivation for the development of electric cars, the age old problem of electric utility, namely, load levelling appears to be another important reason for enthusiasm of electric cars development. It is anticipated that the car owners may recharge their batteries overnight from ordinary domestic sockets.

The batteries option may eventually offer a solution for electricity utility load levelling. But for this purpose the batteries must improve their performance in all departments. The development of electric vehicles, however, may provide only a partial solution for load levelling in a developing country like Nepal since, unlike in advanced countries, the total number of vehicles plying in Nepalese roads is rather limited. But storage batteries for utility load levelling, if successfully commercialised in future, can be adopted for large scale storage of surplus energy in Nepal.

At this stage, it is necessary to stress here that the notion of time element is implicit in the concept of energy storage. It required time periods varying from a fraction of a second to many years in various end-uses. Similarly, from the supply side each energy storage form/method has its own time/scale for storage (Table 4). These time-scales differ from yearly or still longer cycle to a few days or even hours in case of large-scale electric utility load levelling methods discussed earlier. Needless to say, the demand for energy storage period or cycle should match with storage time-scale of selected energy storage form/method for that purpose. In general, if the stored surplus energy will substitute some conventional fuels, then it should match the storage cycle of these fuels.

TABLE 4

SURPLUS HYDROELECTRICITY STORAGE OPTIONS IN DIFFERENT FORMS

Storage Form / Method	End-use Form	Cycle of Storage
A. Electrical Storage		
1. Multiple Dams	Electricity	Yearly or longer
2. Pumped Storage	Electricity	Daily to weekly
3. Compressed Air Storage	Electricity	Daily to weekly
4. Magnetic Storage	Electricity	Very long period
5. Storage Batteries	Electricity	Daily or hourly
6. Capacitors	Electricity	Micro-second to second
B. Mechanical Storage		
Flywheels	Mechanical	Few seconds to few minutes
C. Thermal Storage		
Different media including of fusion	Heat	Daily to seasonal
D. Chemical Storage		
Hydrogen conversion (Gas / Liquid / Hydride)	Heat / Motive power / Light	Daily to yearly.

The next pertinent issue is the form in which the surplus electricity will be stored. Again, there are two different aspects. First of all, the conversion of surplus electricity into any form of storage will result in certain efficiency losses. For example, the pumped storage or compressed air storage schemes involve losses in two stage conversions; pump or compressor losses in the first stage and then turbine-generator losses in the second stage. Such losses vary considerably from one storage form/method to another and that form/method which has the least overall efficiency loss is technically the most superior one. The second aspect is related to the end-use application of stored surplus energy. The concept here is to utilize the stored energy in the same form directly i.e., without converting it to any other form which will involve additional efficiency loss. In other words, the appropriate form for storage depends upon the proposed end-use of stored surplus energy. If the surplus electricity of INPS is earmarked for electrical end-uses, it is certainly most efficient to store it in form of pumped storage or compressed air or storage batteries. On the other hand, if the surplus electricity is to be used as a source of heat to replace other types of conventional fuels, it is not economical to store it in electrical form which has to be converted once again before final application.

These concepts of storage cycle and form for energy storage enable us to arrive at two important conclusions:

1. First, the storage cycle of surplus energy should match the conventional storage cycles of different fuels which will be potentially substituted by it. As the fuels considered for potential substitution are fossil fuels and firewood, a long storage cycle for surplus energy of INPS would be most appropriate; and

2. Second, the real problem of the energy sector of Nepal is scarcity of appropriate sources of heat to substitute fossil fuels and firewood so that the surplus electricity of INPS should be stored not in electrical but in some other appropriate forms which can directly substitute the specified fuels in the given end-use activities.

2.2.4 Storage of Surplus Hydroelectricity in Chemical Form: The Hydrogen Option

Technically speaking, the surplus electricity available in INPS can be stored in several forms as indicated in Table 4 earlier. The preceding section dealt with electrical form of storage and showed that this form is inappropriate for the proposed end-use applications. The same objections can be extended to mechanical form of storage as well since this form also cannot substitute fossil fuels and firewood. That leaves the thermal and chemical storage as the only two appropriate energy storage options in the prevailing conditions of Nepal.

The thermal energy is stored in the form of sensible heat by heating, melting or evaporating various materials. Water, iron, concrete, crushed stones, etc generally serve as the media of storage. These materials do not undergo any physical change themselves and can store heat only at low temperatures. The specified media of storage are appropriate for certain operations such as space heating, which is not an important consideration in Nepalese context. The heat of fusion of some chemical salts enables us to store heat at high temperature required for cooking operation. Similarly, mineral oils and steam or even water under pressure have been used to store heat for cooking purpose in experimental installations. These media of heat storage require relatively complex technology and have considerable difficulties in effective heat transfer. They still need considerable R&D efforts

for economic feasibility. But the thermal heat storage cannot be considered to operate machinery and equipment such as transport vehicles, which is one of the proposed major end-use application for the surplus electricity of INPS in Nepal. This is the main limitation of thermal storage system in the present context.

The chemical energy storage proposed here is in the form of an electro-chemical process. The surplus electricity of INPS will be utilized to produce an appropriate chemical substance through an electro-chemical process which will be later used directly as a fuel in various specified end-use activities. In theory, there are several options to store energy in the chemical form described above by electro-chemical and electro-thermal processes, but the most practical alternative to store surplus electricity is in the form of hydrogen through electrolysis of water.

The electrolysis process is based on the electro-chemical decomposition of water into its components hydrogen and oxygen in a ratio of 2:1 respectively by passing direct current through a dilute aqueous solution of alkali due to the low conductivity of water. The equation is as follows:

$$2H_2O + \text{Energy} = 2H_2 + O_2$$

There are many advantages to convert surplus electricity into hydrogen in Nepalese context which will be elaborated at some length below.

a) Electrolysis as a Simple, Reliable and Mature Technology

Electrolysis has been in commercial operation for a very long period and it is a time-tested technology. Electrolysis are also simple in concept and reliable in operation. They also represent a mature technology. They have long useful life and are easy to operate owing to the simplicity of the process. Hence electrolysis process can be easily adapted in Nepalese context.

b) Hydrogen as an Excellent, Multi-purpose Fuel

Hydrogen has excellent properties as a fuel and competes well with conventional fossil fuels such as petrol, diesel, natural gas, etc. It can be used as an automotive fuel and also as a source of heat in industrial, residential as well as commercial applications.

c) Electrolysis as a Source of High Purity Hydrogen Fuel

Electrolysis of water yields pure hydrogen (99.9 + 0.1% by volume). In fact, it is the only process which produces hydrogen of such purity. In other processes using hydrocarbon-feedstock, the cost of hydrogen purification comprises the major part of the operating cost. The pure hydrogen fuel obtained from electrolysis has high energy content and can be used directly without further purification in all end-uses.

d) **Long Storage Cycle of Hydrogen**

Hydrogen has a long storage cycle and it can be stored over a long period of time. Further, hydrogen can be stored in the form of gas, liquid and metallic hydrides. Each of these storage options has its own advantages and disadvantages, but they still offer wide range of storage options. Hence hydrogen is an appropriate source of energy to substitute fossil fuels and firewood from storage viewpoint.

e) **High Efficiency of Electrolysers**

Industrial electrolysers are usually operated earlier at efficiencies of about 60 to 70 percent. But advanced electrolysers have achieved 90 percent efficiency. Further R&D are undergoing to improve the efficiency of this process to 95 percent or higher.

f) **Flexible Capacity of Electrolyzers**

Electrolysis plants do not have marked scale of economies i.e., the production of hydrogen is not highly sensitive to the plant capacity or scale of operation. Hence electrolysis can be operated at wide capacity ranges without high diseconomies of scale. In fact, industrial electrolyzers range in size from 500 standard cubic feet of hydrogen production per day consuming 3KW of electricity to more than 40 million standard cubic feet of hydrogen per day consuming 240,000 KW (8).

g) **Wide Flexibility in Electrolysis Plant Operation**

Generally speaking, chemical plants take a long time to achieve their rated capacities once their operation is interrupted for any reason. But this is not the case with electrolysis plant, which unlike other chemical processes, achieves its rated capacity rather quickly after its start-up. Hence electrolyzers can be switched on or off according to energy supply situation in INPS. Thus electrolyzers can be ideally dovetailed with electrical system.

Further, the hydrogen production load can be discontinued in future if productive industrial or commercial loads would emerge that will purchase surplus electricity at full electricity tariff. But this is not likely to happen since a captive demand may not emerge for seasonal energy due to the reasons specified earlier.

h) **Scope of Increasing Economic Efficiency of Hydrogen Production Through Co-product Credits**

It takes about 4 Kwh of electricity to produce 1 Nm^3 of hydrogen by common industrial electrolyzers. As such, electrolysis is considered as an expensive technology. Although the development of advanced electrolyzers have considerably increased the efficiency of this process, the consumption of electricity still remains relatively high. The high consumption of electricity, however, may not be a major concern in case of surplus electricity available in INPS, which is otherwise wasted in the given system.

In this context, it should be stressed that electrolysis produces two co-products, namely, hydrogen and oxygen. The production of oxygen is half the quantity of hydrogen and it is 99.5 + 0.1 percent by volume pure. As the two gases are simultaneously produced, it is reasonable to refer the power consumption for both gases (H_2+O_2). Generally, the pure oxygen is vented to atmosphere due to the lack of captive demand for this product in large-scale installations. Thus the lack of oxygen credit in almost all cases increases the overall generation cost of hydrogen. Hence the feasibility of electrolysis to a high degree depends upon the utilization of co-product oxygen. Thus the application of oxygen in small or medium scale industrial operations such as cutting and welding or combustion processes will considerably enhance the overall economic performance of electrolysis, particularly in small installations.

Heavy water or deuterium, which is used as a moderator in nuclear reactors, can also be produced as a by-product of electrolysis. It could further improve the economic efficiency of hydrogen production provided that there is demand for this product in export market. The storage of surplus electricity in form of hydrogen thus appears as the best solution for country like Nepal.

2.3 Synergetic Effects of Hydrogen Production from Surplus Hydroelectricity

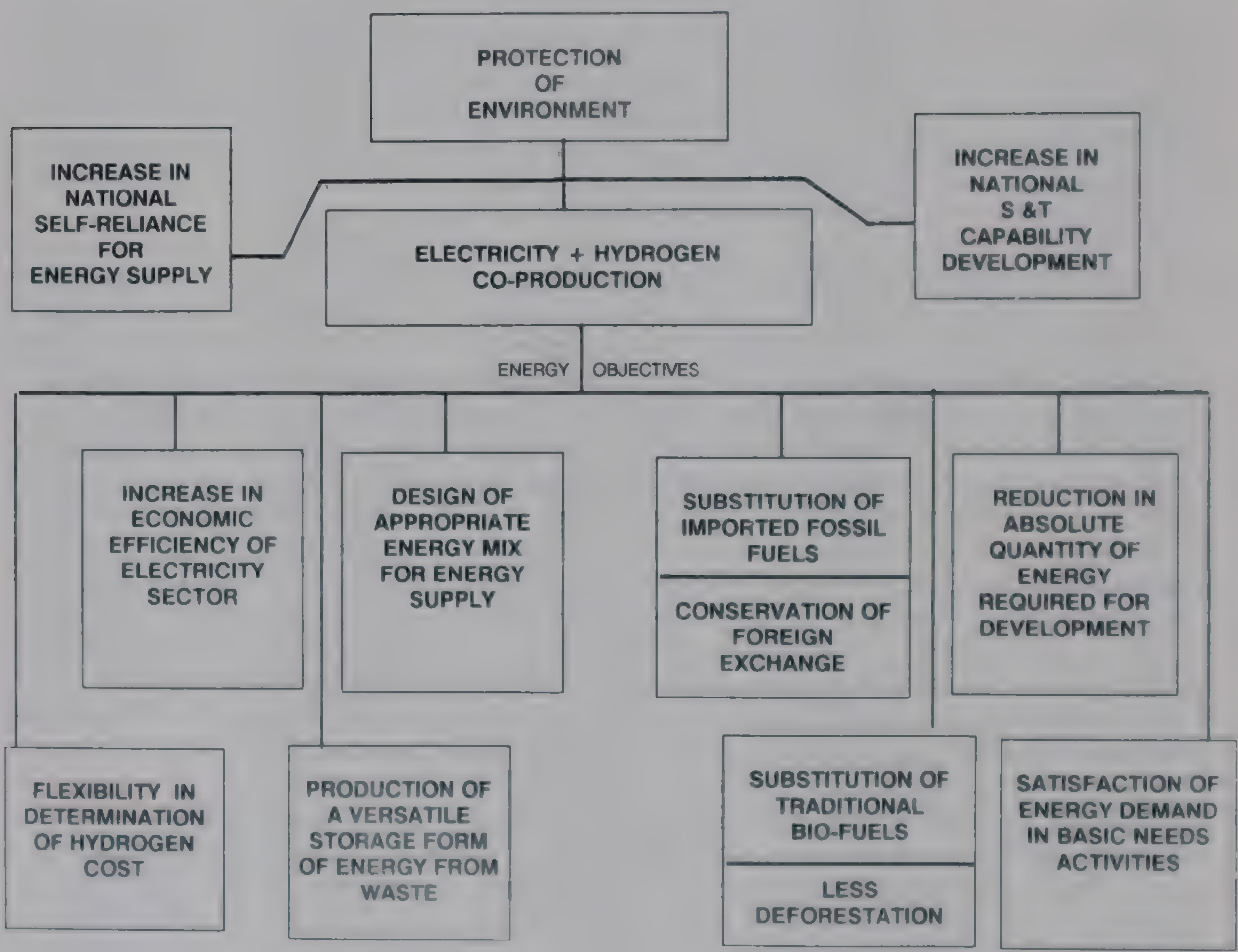
The production of hydrogen from the available surplus hydroelectricity in INPS offers a unique opportunity for synergism which can produce wide ranging impacts on the energy sector of Nepal. By definition, a synergetic solution is one where the combined and cooperative effect of measures relating to two or more activities is different and preferable to the sum of the effects of uncoordinated and separate measures. As stated earlier, the electricity sector in Nepal is characterised by surplus or waste energy and hence it is not very efficient as a separate entity. On the other hand, the production of hydrogen by electrolysis process, if envisaged as a separate activity, will certainly not be economic either due to the prevailing high electricity tariff in Nepal. But if the surplus energy available in INPS will be utilised for hydrogen production or the hydrogen will be conceived as a co-product of electricity generation, this combined and coordinated measure will produce entirely different and more preferable result due to synergism.

Synergism has many effects which are summarized in Figure-2 into two groups i.e., synergetic effects on energy sector and non-energy sector. We shall elaborate these effects at some length here. While some of the synergetic effects are minor ones, others can substantially tilt the existing, delicate balance on favour of hydrogen. First of all, concept of hydrogen as a co-product of electricity sector offers a wide range of flexibility in the fixation of factor cost of inputs as well as the capital costs (depreciation) of electrolyzers. As a rule, the hydrogen generated from the electricity will inevitably be more expensive than the electricity that produced it. But in this case the production of hydrogen will utilize the surplus energy available in the system which is otherwise wasted. The cost of electricity input is, therefore, bound to be flexible in this context. Similarly, the depreciation of electrolysis plant is not solely determined by the life span of the assets due to physical deterioration but more by the government regulations (incentive for quick recovery of fixed capital investment) as well as company policies. Hence the synergetic effect could enable hydrogen production at much lower cost than under normal circumstances and thereby make economics of hydrogen much attractive for fossil fuel substitution.

The economic viability of hydrogen generated from the surplus electricity to substitute fossil fuels and firewood depends upon a host of socio-economic and technical factors which are not known at this stage. These aspects do not also fall within the scope of present study. Nevertheless, some tentative conclusions are forwarded here basically to illustrate the synergetic effect of electricity-hydrogen co-production on the cost of hydrogen.

The production cost of hydrogen is largely determined by two factors: a) cost of electricity; and b) depreciation of electrolysis plant. In fact, these two items generally comprise as much as 90 percent or more in the total cost of hydrogen production. Both of these cost items, which are generally considered as exogenous variables under the separate provisions for hydroelectric scheme and hydrogen plant, become rather very much flexible when these two schemes will be combined together as a single project as proposed earlier. On the one hand, the tariff of surplus electricity is highly flexible within two extreme limits; the upper one set by the existing tariff for industrial application and the lower one being zero. On the other hand, the useful life of electrolysis plant is very much longer than 10 to 12 years which is conventionally adopted for calculation of depreciation (many electrolysis plants are normally operating even after 25 to 30 years of service all over the world) so that it can be relaxed and a lower than conventional rate of depreciation can be enforced. It may be possible to promulgate special legislations, if required, for this purpose. Thus these two items, namely, the tariff of surplus electricity and the rate of depreciation of electrolysis plant, when combined together will offer very wide leverage for determining the production cost and thereafter sales price of hydrogen. Hence, in all probabilities, hydrogen can be a real, economic alternative to substitute other conventional fuels in Nepal due to these synergetic effects.

FIG.2 SYNERGETIC EFFECTS OF ELECTRICITY-HYDROGEN CO-PRODUCTION



Now we shall briefly examine the synergetic effects of electricity and hydrogen co-production on electricity sector. Needless to say, the electricity sector will be tho first major beneficiary of the synergetic effects. The hydrogen co-production from the available surplus energy in INPS will save waste energy. It is always cheaper to save energy than to generate it. In fact, the hydrogen co-production with electricity will not only conserve the waste energy but also increase the overall load factor or the economic efficiency of the system. At the same time, it will also generate additional revenue to the electricity authority, even if the surplus energy may be valued at less than the prevailing tariff of electricity in Nepal. This additional revenue will help improve the financial health and solvency of electricity undertakings. The synergetic effect could also make the judiciously designed small hydro development schemes economically more attractive by producing both electricity and hydrogen for decentralized applications. In contrast, the present power transmission and distribution costs from the central electric grid to rural areas are excessively high due to small load due to small load densities and load factors.

Above all, the issue of economic efficiency is of vital importance. Economic growth is an essential condition for development and the hydroelectric system - the most important energy supply system in the country-must be highly efficient in order to support economic growth in the country. The present state of affairs, however, suggest that the electricity sector is not capable even to support its own growth. This is the paradox of the energy sector of Nepal. Needless to say, the social costs of buttressing economically inefficient technology are very high which cannot be sustained for ever. While the imperative to develop hydroelectricity; the most important energy resource in the country, is essentially recognized at all quarters, the actual development of this sector has been hampered by many factors, both internal and external, among which the present economic performance of this sector is not of least importance. As such, there is a genuine apprehension that the electricity sector will remain inefficient as long as the present trend in generation and consumption will continue to persist. Hence it is essential to intervene with some measures to modify this pattern of generation and consumption. Hydrogen could serve as an ideal mechanism for this purpose.

The energy sector as a whole will also substantially benefit from the synergetic effects. The co-production of hydrogen will supply another type of storable fuel which can find much wider application than electricity itself. In other words, the synergetic effects will enable production of an altogether new type of storable energy source (hydrogen) from the surplus or waste of one source (electricity) so that instead of a single, traditional source we have at hand two types of energy sources which are highly complementary to each other. Hydrogen is a versatile energy source which can be used in automotive, domestic, industrial and commercial applications. As a multi-purpose fuel, hydrogen can serve as the key component for the required energy mix in Nepal. Thus hydrogen and electricity together make an ideal energy mix which can potentially substitute all other types of traditional and fossil fuels in use in Nepal. Hence the co-production of hydrogen from surplus electricity offers an ideal opportunity to design an appropriate energy mix with electricity that can supply energy to all basic needs oriented end-use activities in Nepal. Viewed from this perspective, hydrogen appears as a panacea for relieving both kinds of energy "crisis" in Nepal, namely, the "firewood crisis" in the informal sector as well as the "fossil fuel crisis" in the formal sector. At the same time, the co-production of hydrogen from surplus electricity can achieve other important non-energy objectives such as conservation of scare foreign exchange, self-reliance on energy supply, etc.

The hydrogen-electricity energy mix can thus substantially modify the existing patterns of energy production, distribution and consumption in Nepal and shift them towards the path of sustainable development. Hydrogen thus appears to a catalyst for change towards sustainable development. In fact, the hydrogen scenario accelerates the process of transition towards sustainable development within a short time span.

The next effect of synergism is the substitution of imported fossil fuels which are at present mainly used in a) transportation (high speed diesel, petrol, aviation turbo fuel, etc), b) household (kerosene for lighting and cooking purpose), c) industry (light diesel oil, furnace oil, coal, etc) and d) agriculture (diesel). The transport sector consumes the bulk of imported oil. The oil consumption in Nepal is mainly represented by two middle distillates, namely, high speed diesel and kerosene. As regards the use of fossil fuels in industrial sector, they are mainly used to provide process heat in organized industries for various applications such as steam generation, hot water supply, kiln operation, etc. These fossil fuels can be technically substituted with hydrogen. Hence it could be concluded that hydrogen has the potential to substitute the bulk of imported fossil fuels in Nepal.

The substitution of traditional biofuels used for rural domestic cooking purpose is another important effect of synergism. Hydrogen can potentially replace biofuels even though there are serious social as well as techno-economic barriers for this purpose.

One of the major issue for sustainable development is to reduce the absolute quantity of energy required for development purpose. In other words, the imperative at this stage of development is to achieve the same level of welfare and comfort at much lower rate of energy consumption than practised today. This statement may appear paradoxical, but it is true. The present per capita energy consumption in Nepal, though extremely low by the international standard, cannot be maintained at this level of consumption let alone be increased proportionately with the population growth in the country. The biofuels consumed today has extremely low efficiency of utilization, particularly in domestic cooking operation, which is apparent from the very large quantity of biofuel consumption in Nepal. This is a sheer wastage of resources which is clearly avoidable.

Under the given circumstances, it is difficult to imagine how the present pattern of biofuel consumption can continue through the next century without ecological catastrophe. Nevertheless, the response to this dilemma has been lukewarm. The ecological disintegration, however can only be averted by a shift in domestic energy consumption towards sources which have higher energy densities as well as end-use efficiencies. Hydrogen fulfils these criteria and can substitute the bulk of biofuels in cooking operation with much smaller amount of energy mainly by performing the same service with smaller but more efficient use of energy than in the former case.

The experimental performances of hydrogen technologies have been quite encouraging in this respect. For example, hydrogen as a fuel has reportedly given much higher performances both in terms of brake thermal efficiency and kilometres travelled per unit of fuel consumption than the conventional petrol engine. Hydrogen lighting as electricity, gas or by condoluminescence is expected to be far superior and more efficient than kerosene lighting. Similarly, hydrogen consuming gas stoves (catalytic cookers) could have an efficiency of 100 percent as against the highest of about 50 percent for pressurized kerosene stove and 10 percent for traditional domestic cooking stoves. Thus hydrogen energy is expected to fulfil the same task at much lower level of energy consumption in comparison to traditional biofuels. Hence the synergetic effects of electricity-hydrogen co-production will support sustainable development through the reduction in absolute quantity of energy required for development.

The synergetic effects will also contribute to the satisfaction of basic needs of the population. Energy consumption is not an end in itself. It is only a means to provide services to various human economic activities. Since each human activity is directed towards the satisfaction of a certain need, it is pertinent to ask who consumes the energy and for what purpose. These questions are particularly important in Nepalese context where the present energy consumption pattern is very much skewed towards the affluent section of the society. On the other hand, the basic needs of the poor households, which represent the bulk of the population in the country, is largely ignored. But the large scale deforestation and the impending ecological crisis cannot be checked until and unless the energy problem of the poor, particularly the cooking fuel, is not properly addressed and solved. The hydrogen alternative offers a solution in these respects by providing both automotive and domestic fuels which are directly related to basic need activities.

Now we shall turn to non-energy effects of synergism which deal with protection of environment, development of national scientific and technological (S&T) capability, and national self-reliance in energy supply. All these issues are intricately related to sustainable development.

In a nut-shell, population explosion, mass poverty and low economic growth are mainly responsible for environmental degradation in Nepal as elsewhere in other developing countries. In addition, the large-scale adaptation of western technologies and life styles in Nepal have further aggravated the environment. Moreover, the political and economic systems have so far equated 'economic growth' with development as if they are identical. But growth does not imply development and the obsession with growth has led to more destruction of environment. The apparent contradictions between economic growth and environment still persists which further marginalises the people and degrades the environment. In this context, the production, distribution and consumption of energy are directly responsible to many "external" impacts on environment. But hydrogen is a clean energy. The production of hydrogen via the electrolysis of water has no adverse environmental impacts. The small-scale distribution of hydrogen in form of gas, liquid or hydrides also does not pollute the environment. The consumption of hydrogen in the proposed end-use activities (automotive use, domestic cooking, etc) are expected to substitute fossil fuels or firewood and thereby significantly reduce the present level of pollution originating from these fuels. Hence the synergetic effects of hydrogen co-production are highly positive on environment.

The hydrogen option has important implications on national S & T development. Hydrogen is a hazardous material as any other fossil fuels. In fact, it is more hazardous than other conventional fuels. Hence the production, storage, distribution and use of hydrogen require relatively high technology. The successful application of hydrogen in Nepal is possible only if the technologies currently available in the global market can be transferred and assimilated in the country. As a mater of fact, the mere access to existing technologies may not be enough; it will be essential to adapt these technologies in local context for providing rational solutions to energy problems of Nepal. Hence the synergetic effects of hydrogen production and application in Nepal will strengthen the national S&T development capability of the country.

Finally, the self-reliance in energy supply is a vital issue of national importance which cannot be expressed in monetary or economic terms. It is meaningless to ask what price a nation is willing to pay for its security and sovereignty. The vulnerability of Nepal with regard to reliability and security of oil supply was exposed by the trade impasse between Nepal and India in 1988/89. The profound economic, political and psychological effects and hardship experienced by Nepal due to the dependence on oil supply need no

elaboration here. But the burden of oil import is increasing on the scarce foreign exchange reserve and the chronic adverse balance of payments situation of the country. In reality, the increasing volume of foreign debt has not only made debt servicing difficult but also invited the external institutions to intervene in our internal policy matters. Under these circumstances, the synergetic effects of electricity and hydrogen co-production could considerably reduce the vulnerability of Nepal by offering a solution, however partial it may be, to attain the national self-reliance in energy supply. The political and economic effects of this measure on Nepalese psychology cannot be exaggerated.

In conclusion, the synergetic effects of electricity hydrogen co-production offers Nepal a unique option for an entirely different soft development path towards greater self-reliance and sustainable development.

2.4 Possible Implications for Hydrogen Technology Applications in Nepal

The application of hydrogen as an energy alternative for day to day use is still considered rather exotic despite its high tonnage production and consumption in industry. Besides the cost factor, the safety consideration in storage and handling seems to be other main restriction for using hydrogen as a fuel in automotive and domestic purposes. The storage and handling problems of hydrogen, however, have been satisfactorily solved for industrial application. But it appears difficult to enforce the same rigid specifications in design and safety regulations in operation and maintenance of machinery and appliances earmarked for individual consumer or household. Nevertheless the required technologies for safe storage and handling of hydrogen in small-scale have already been developed and marketed, even though they are still very costly for common use. Hence the application of hydrogen technology in Nepal does not necessitate to reinvent the wheel.

The main problem for application of hydrogen in Nepal is to identify proper areas of use and then design appropriate technologies for these particular uses. The first issue is to judiciously identify the areas in Nepal where the application of hydrogen can be economically competitive with other conventional fuels under the given conditions of demand and supply. The second issue is to fashion out new technologies by original combination of existing components in the market for the specified uses. A certain degree of technological capability within the country is essential for this purpose. While both these issues are important for the successful application of hydrogen as an energy alternative in Nepal, the present limitations in the S&T capability of Nepal pose considerable restrictions for appropriate technology supply. The implication is that the technology supply will considerably depend upon the goodwill and co-operation of industrialized countries as well as international agencies.

Under these circumstances, one of the major concern is the likely evolution of hydrogen end-uses since it could either help meet the basic needs of the masses or encourage the consumption of imported luxury goods by the local elites. The issue is very sensitive because the use of hydrogen is advocated in Nepalese context to solve the crises of dual of society which is marked by glaring inequities. On the one hand, hydrogen has been offered as a potential solution for "firewood crisis" where it would provide cooking energy (together with lighting) to rural subsistence economy. But in reality, hydrogen as a commercial fuel is likely to find application in urban sector and in trekking tourism. On the other hand, hydrogen is expected to alleviate the "oil crisis" by substituting oil in the modern transport sector which symbolizes the energy consumption pattern of western society, but the solution offered by this measure will be entirely different depending upon whether hydrogen would replace oil in mass transportation vehicles (buses and trucks) or in passenger cars.

Despite the extremely high attractiveness of hydrogen as an energy alternative in Nepal, the techno-economic feasibility as well as social acceptance of this option have yet to be evaluated. In this respect, the techno-economic feasibility will depend upon a host of factors such as:

a) Cost of hydrogen generated from surplus electricity in INPS;

b) Price of hydrogen based machineries as well as appliances (engine for automotive purpose, domestic cookers, lights, etc) together with their useful life;

c) Specifications for hydrogen consumption by these machineries and appliances in given end-uses or their efficiencies;

d) Handling and storage safety of hydrogen in small-scale applications;

e) Comparative economics of hydrogen and other conventional fuels application in specified end-uses; etc.

While the techno-economic feasibility of hydrogen technology can establish in some judiciously selected areas of application, the social acceptance of this technology remains an enigma. Hence hydrogen should not be simply viewed as a technocratic solution, but a holistic approach should be taken for its promotion. The technological intervention with hydrogen as a new energy alternative into the existing production systems, both urban and rural, will necessarily have many social engineering consequences which need to be properly studied and analyzed.

While the government and outside agency can create awareness and opportunity for a social change through a technological intervention, whether that particular social change takes root in a given community or not will depend upon the attitudes and motivations of that community towards it. By and large, these attitudes and motivations are governed by their own "felt needs" and perceptions of social goals. In this respect, the application of hydrogen technologies is likely to have very much different social implications in different end-uses. While the automotive use of hydrogen in mass transport vehicles is not likely to encounter any serious social resistance, the hydrogen cooking can be an entirely different proposition. Cooking is deeply rooted in the cultural tradition of a society. Although the Nepalese people are, by no means, known for their gastronomy, the different ethnic and cultural groups have considerable diversity in food habits and recipes. Further, the capacity of the cooker as well as cooking pots have to be adopted according to the family size. As the hydrogen cooker is essentially a gas cooker, it is expected to solve these problems with appropriate modifications in technical design. Nevertheless, some social objections may arise due to the change in the flavour of cooked food (e.g., in comparison to traditional cooking over open fire) or due to the invisibility of hydrogen flame during cooking operation.

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IV. COUNTRY EXPERIENCES

ELECTROLYTIC HYDROGEN POTENTIAL IN CHINA

Liu Hongyun

Abstract

Since 1985, China has been carrying out its ambitious Rural Electrification Program on Large Scale giving an impetus to the rapid development of medium and small scale hydro power plants and local electric grids. Many hydro plants in service, however, are of run-of-the river type, being able to provide considerable amount of surplus seasonal energy for which no other market exists. In spite of several methods used to increase the use of this surplus seasonal energy, still much unused water has to be released through spillways. With the rapid increase in hydroplants starting operation and the availability of off-peak hydro electricity at a low cost, the situation in China's rural areas appears very favourable for water electrolysis and hydrogen production development.

1. Introduction

In the past decade, the rural economy, especially the township and privately-owned enterprises in China has developed at an amazing speed experiencing double digit growth one year after another. In addition, parallel demands for higher standard of living has made electrical appliances, such as TV sets, refrigerators, electric fans, washing machines, etc. increasingly popular in farmer's houses. Obviously, this unprecedented growth of rural economy and popularity of electrical appliances must put high pressure on the power supply. China has faced more challenges keeping rural businesses going speedily - without interruption caused by serious power shortage.

1.1 Rural Electrification

In response to the sharply rising demand for electricity in rural areas, the State Council has made a National Rural Electrification Program (REP), accelerating power generation and accessibility to promote rural economy and to make a better life for rural population. For the first stage of REP from 1985 to 1990, the State Council approved 100 counties for rural electrification. With the financial support from central and provincial governments, these counties, mainly through developing their own power generation projects with associated power lines and substations, should meet, among others, the following basic requirements by the end of 1990.

1. Electricity available for not less than 90 percent of households in each county

2. Electricity consumption per capita of atleast 200 kwh per year

3. Domestic electricity consumption per household of 200 kwh per year

4. 20 per cent or more households using electricity for cooking

1.2 Hydro Power Options

In the efforts of achieving the goals set up by the State Council, the 100 pioneering REP counties could not consider the possibility of nuclear power for evident reasons. With regard to thermal power, China does have immense reserves of coal, which has been the nation's traditional primary source of energy, but its geographical distribution is uneven; a mere several per cent of the national total reservers are found in the South where most of the 100 pioneering counties are located. Besides, high cost caused by long distance transportation of fuel and environment pollution from small thermal power plants should be taken into account. Obviously, coal-fired generation could not serve the purposes. Fortunately, China has rich hydropower resources with more than 3000 rivers and streams, each having a potential to produce 10 MW or above. The nation's theoretical hydropower potential is 676 GW, corresponding to an annual power generation of 5920 Twh, while its total exploitable potential being 378 GW, corresponding to an annual generation of 1920 Twh. Details in this respect for each region in China are listed in Table 1. From which it can be seen that above 80 percent of the national hydropower potential concentrates in the South.

Table 1 - Hydrogen Potential in China

	Theoretical potential (1000 MW)	Exploitable Potential		
		Installed capacity (1000 MW)	Electricity generation (TWh)	Percentage (%)
North China	12.30	6.92	23,225	1.2
Northeast	12.12	11.90	38,391	2.0
East China	30.05	17.90	69,794	3.6
Central South	64.08	67.43	297,365	15.5
Southwest	473.31	232.34	1,305,036	67.8
Northwest	84.18	41.94	190,493	9.9
Total	676.05	378.53	1,923,304	100.0

Under these physical circumstances, hydropower is the answer to 100 pioneering counties for their rural electrification, being able to provide 90 per cent of their power need. By the end of 1990, 109 counties had met the requirements set up by the State Council for REP. In addition, another 200 counties have been included in the second stage of REP, beginning from 1991.

Due to the implementation of the REP schemes as well as the rapid development of small and medium hydro power projects in the rural areas, by the end of 1990, the total installed generating capacity amounted to 13,180 MW with an annual generation of 38.28 Twh.

1.3 Seasonal Surplus Energy

Large scale hydropower development in China's rural areas has its disadvantages as well. First, although, yearly mean precipitation usually exceeds 1000 mm in the South, but with a uneven seasonal distribution, rainfall in wet season from April to July accounts for two thirds of the annual total (2) necessitating large regulation capacity from storage dams. On the other hand, however, high density of population, in many cases percents high dams from being built a potential sites. Very often, a scheme with a high dam had to be replaced by one with a series of low dams to decrease the number of people to be affected. As a result, majority of hydroelectric stations are of run-of-the river type. Furthermore, these power stations operate usually in isolated regional power grids or in those with limited interconnection to a large grids. Therefore, the regional grids with predominant run-of-the river hydro plants inevitably present hydro power surplus in wet season. In our practice, this problem has partially been solved through the following measures adopted in light of individual conditions (3).

- Head-water storage and inter-basin pumped storage under favourable topographical conditions

- Seasonal loads

Irrigation and drainage using pumpsets for rice farmland are the most desirable seasonal load, since rice-growing season coincides with the high-flow period of rivers in China's South. In addition, ferrosilican production and other similar industries with high power consumption also are among major seasonal loads in rural areas.

2. Electrolytic Hydrogen Energy Potential

Despite the fact that the above mentioned measures commonly adopted for China's many local grids could consume a significant portion of surplus energy, however, much of it still remains unused. As a result, generating units have to limit their output, frequently operating at part load, while a considerable amount of water is wasted, releasing through spillways. The total installed generating capacity of hydro plants in China's rural areas, as mentioned above, amounted to 13,180 MW with an annual generation of 3,928 Twh in 1990. On the other hand, fall-load operation time for the hydro plants was generally designed in the range of 4000 to 5000 hours per year. In other words, additional generation of 1.34 Twh, or one third increase could be produced if adequate consumers could have been provided.

According to the Ministry of Water Resources who is in charge of rural electrification and hydropower development in China's rural areas, hydroelectric power in the rural areas is set to increase in the 1990s, from 13180 MW in 1990 to 28180 MW in 2000, namely an annual increase of 1500 MW on average. For the same reasons, most of the hydroelectric stations built or to be built in the period from 1991 to 2000, very likely are of the run-of-the-river type, capable of producing surplus seasonal energy proportional to that from existing hydroplants in the rural areas. Usually, hydropower plans are designed with a full-load operation hours (the annual generation divided by the installed generating capacity of the powerplant) ranging from 4000 to 5000. Assuming that the actual full-load operation hours of the power plants coming into service in 1990s remain approximately 3000 on average, the same as the existing power plants, the surplus seasonal energy can be estimated to be 20 to 41 Twh in 1995 and 28 to 56 Twh in 2000. Such a considerable amount of energy must not be wasted. However, electricity, as well known, cannot directly

be stored. Hydrogen, another form of secondary energy, has the advantages with regard to storage and transportation. Consequently, hydrogen can serve as an energy carrier that is now being considered as a complement to electricity. The most commonly used method of producing hydrogen is by electrolysis. There are large electrolyzer installations producing hydrogen in many countries. In order to increase the efficiency and economic benefits of hydropower plants by making use of the surplus seasonal energy as full as practicable, the surplus seasonal energy can first be converted at hydro power plants to hydrogen through the electrolysis of water. Chinese hydrogen market is difficult to give an exact evaluation due to a lack of relevant data available, but there are basically three potential sectors for electrolytic hydrogen consumption:

a) **Retail**

Chemical and pharmaceutical industries, electric machine cooling, thermal treatment of metals, etc.

b) **Ammonia synthesis**

The ammonia needed to manufacture fertilizers and other chemical products, is responsible for the most of the hydrogen consumption. Presently, ammonia production plants in China mainly utilize coal, natural gas or oil derivatives as raw material. Faced with a continuous growth in the demand for fertilizers by rapidly expanding agriculture, China has to import a great amount of fertilizers each year. The surplus seasonal energy could be used to produce hydrogen for ammonia synthesis, and much of fertilizers imported could be reduced.

c) **Power Generation via Gas Turbines (4)**

The concept of hydrogen production and its utilization directly at power plants is based on the following principle: Through the electrolysis of water, surplus hydroelectric energy produced by generating equipment will first be converted to hydrogen, which can be stored in gas or liquid form. When necessary, the stored hydrogen will be converted through gas turbines and associated generators. Gas turbines have many advantages, such as quick start, low investment cost, low maintenance and short delivery time. It is assumed that the proposed system will produce hydrogen in off-peak time and in time of high river flows when excess energy would otherwise be wasted. Apparently, the stored hydrogen will be used to generate daily peak-load energy or electric energy in dry season when the river flows are ordinarily low, resulting in low output from hydropower plants. The electricity rate difference between the base-load energy and the peak-load energy varies widely from province to province, but in average terms the ratio is about 2 to 6 and the ratio of the rate in dry season to that in wet season is about 2 to 4. It should be pointed out that the utilities in China, very often, refuse purchase of the seasonal energy, forcing hydro plants to release a great amount of water through spillways and outlets. This explains why full-load operation hours for most hydroplants have been much less than designed. Considering this fact, hydrogen production and utilization at hydropower plants, undoubtedly will bring much economic benefit to the hydroplants and their regional power grids, in addition to much improvement on the availability, reliability, flexibility, safety and efficiency of regional power system operation.

3. Conclusion

China's National Rural Electrification Program has given an strong impetus to the rapid development of hydropower plants, most of which are run-of-river type. The regional power grids with predominant hydropower plants could provide a great amount of surplus seasonal energy for which unfortunately, no other ready market exists. This calls for new ways for more effective use of the surplus seasonal energy instead of wasting it as it is. Hydrogen production through the electrolysis of water can significantly reduce the waste of surplus seasonal energy. Hydrogen produced can be stored or transported as a commodity, and can be used at the site through the hydrogen production-utilization system, which is technically and economically feasible, and could bring much benefits to hydropower plants as well as local power grids.

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PROSPECTS AND PERSPECTIVES OF HYDROGEN ENERGY PROGRAMMES IN INDIA

O.N. Srivastava

1. Background

Hydrogen, an energy capable of being used in all the energy sectors where presently fossil fuels like petroleum and coal are in service, is a comparatively new entrant on the renewable energy scenario. In sharp contrast to fossil fuels, it is inexhaustible, pollution free (no Green house effect or Acid Rains), free from market monopoly and renewable/source regenerating. The last aspect is very crucial. Hydrogen is produced from a certain quantity of water drawn from earth is inventory, upon usage (e.g. burning in I.C. engine), the same quantity of water is returned back to the inventory. This renewability/source regenerating aspect associated with hydrogen, puts it ahead of other possible alternative fuels, like compressed natural gas. It is generally believed that hydrogen may first enter as a substitute for petroleum in the transportation sector. At a later stage, its versatile properties may be used for other purposes such as electricity generation, cooking gas, etc. Hydrogen is an intermediary form of energy; it is an energy carrier between the primary energy source (like solar, wind, nuclear, etc), and the energy consuming sectors or users. The storage and the transmission systems and conversion devices related to hydrogen remain the same, even though the primary energy sources may get changed due to various factors such as availability, economic viability and geographic location.

There are three specific factors which favour fostering of hydrogen in place of fossil fuels e.g. petroleum or coal.

(i) The huge consumption of fossil fuels is degrading the environment by the Green House Effect originating from the increase of carbon dioxide content ($22x10^9$ man made tons per year) due to excessive burning of coal. The GH effect leads to Global warming which results in the temperature rise of about 3°C by the year 2005. Yet another detrimental effect 'the acid rain' caused by releasing of sulphur and its reaction with H_2O_2 leading to H_2SO_4.

(ii) The fossil fuels besides being dirty are also fast depleting. The recent estimates suggest that petroleum would become depleted to non-existent level in about 50 years. In our country the petroleum production in Bombay High has already peaked and new potentially projected source would be grossly inadequate to match demands (a total of 86 MT by 2000).

(iii) Another aspect favouring the commencement of 'Hydrogen' era is the economic factor. The price uncertainties arising from political instabilities in Middle East where most of the oil deposits are located leads to market monopoly which causes sharp price rises (remember the first, second and third oil crises in 1973, 1979 and 1990). A price increase by 1$ per barrel leads to a rise of our export bill by about Rs.470 crores. In 1991, our total oil requirement is about 59 MT and out of this 30 MT will have to be imported. The recent price rise amounts to an increase in the import bill by about Rs.8000 crores. In the year 2000, we would need about 85 MT of oil and out this 45 MT will have to be necessarily imported. Thus at

present as well as in future our economy is crucially dependent on the oil import. The total oil import bill will have to be decreased, to get out of the international borrowing and to leave room for the availability of foreign exchange for other crucial sectors like defence, high priority R and D, public health, etc.

Whereas all the three factors cited above suggest an urgent transition to an alternative fuel, the best out of which is undoubtedly hydrogen, it is the first factor, namely the environmental degradation, which is the most compelling cause for the said transition for developed countries, e.g. U.S.A., Germany, Japan etc. However for India, it is the third factor namely 'Economic Aspect' which makes imperative the urgent introduction of the 'hydrogen energy' more particularly 'hydrogen as Fuels' i.e. as 'substitute for petroleum'. Some salient features of 'hydrogen' outlining its advantages are outlined in the following:

The two important sources of commercial energies which are presently being maintained, through production of fossil fuels are electricity and petroleum. Both of these need replacement by renewable. In view of this, besides the development of renewable energy sources aimed at producing electricity e.g., through photovoltaics, wind energy, fuel cells, 'MHD', etc. renewable capable of replacing the polluting, depleting and economy destabilising conventional source, the petroleum, will also have to be developed. Where as fossil fuel produced energy sector there are several renewable alternatives as outlined in the above for petroleum replacement the choice of renewable is rather limited. Out of the various possible alternative to petroleum such as methanol, ethanol, natural gas (e.g. CNG), natural gas liquids (e.g. propane), syn. gasoline, hydrogen etc., the only candidate which is ecologically compatible (pollution free), inexhaustible and completely renewable, is hydrogen. A qualitative comparison of hydrogen with some other renewable is outlined in the following:

i) Unlike several forms of renewable e.g. MHD and fuel cells, R and D demonstration projects for hydrogen energy is not cost intensive. The required expenditure may be less than three to ten times the cost for others.

ii) Unlike wind and microhydel, hydrogen energy is not site specific.

iii) Where as other renewable energies and devices such as photovoltaic, fuel cells, and wind power, would produce electricity, hydrogen is a complete energy vector. It can be used as a substitute for petroleum but can also be easily converted through fuel cells to electricity.

iv) Where as there is generally a problem related with storage in solar forms of renewable energies e.g. photovoltaics and wind energy, hydrogen can be easily stored as reversible hydrides or liquid hydrogen.

v) Unlike other renewable, hydrogen can be produced by off-peak electricity in the industrial belts, by PV power in remote areas (deserts, hills etc.), by wind power in coastal areas by nuclear power.

2. Cost-Factor and Hydro Potential

Every form of non-conventional renewable energy has to compete in price with the present conventional (fossil) energy. Table 1 estimates the clean renewable energy carrier hydrogen in various contexts.

Table 1

Price Estimates of Energies, Indian - Context

A.	Energy	Approximate Estimate
	1.Electricity (Rs1.5 KWh)	Rs 408/GJ
	2.Gasoline (Rs 16/1)	Rs 480/GJ
	3.Hydrogen (Naptha Cracking)	Rs 440/GJ
	4.Hydrogen (Electrolytic)	Rs 1530/GJ
	5.Hydrogen (PV)	Rs 1200/GJ
	6.(a) Hydrogen (Hydro-grid, Normal)	Rs 1530/GJ
	(b) Hydrogen (Hydro-decompled Rainy Season - 4 months)	Rs 1530/GJ
	(c) Hydrogen (Micro & Mini Hydro, off peak)	Rs 700/GJ
B.	1.Gasoline Rs 16/1	Rs 22/Kg
	2.LPG (Cooking Gas)	Rs 5.4/Kg
C.	Hydrogen Distribution to Vehicle/LPG Cylender in the form of Hydride Rs 1530 + Rs 500	Rs 2030/GJ

As may be seen from Table 1 that the hydrogen power induced water electrolysis leads to hydrogen which appears to become cost competitive with fossil fuels like gasoline (LPG). It will be opportune to refer briefly to hydro power potential in India. Table 2 gives total hydro power potential as estimated in 1990. Of this only about 20% is presently installed.

The Indus, Ganga and Brahmaputra river basins of the Himalayan region together with rivers of the Peninsular India, drain a total area of 2,50,000 sq. kms. The average annual flows from these basins has been assessed as about 180 million ha m. The magnificent relief together with enormous water flows in the various river system of India present huge hydropower endowment. The Himalayan rivers such as the Great Indus, Ganga and Bhramaputra constitute about 70% of the total assessed hydro potential of India.

Table 2

Hydropotential - Indian River System

River System	Hydro Electric Potential (MW at 60% Load Factor)
Indus	19,988
Brahmaputra	345,920
Ganga	10,715
Central Indian River	2,740
West Flowing River	6,149
East Flowing River	9,532
Total	84,044

Of the above the present tapped and installed capacity correspond to about 18,612 MW i.e. about 20% of the total assessed. The installed capacity details are shown in Table 3.

Table 3

Installed Hydroelectric Capacity

Region	Installed Capacity (MW) (as on 30.06.90)
Northern	6097.39
Western	2228.31
Southern	8129.01
Eastern	1429.06
North Eastern	423.35
Upto March 1990	18307.12
Upto March 1992	18612.90

Some of the important storage type hydro-power plants are Bhakra (1200 MW), Pong Dam (360 MW), Rihand (330 MW, Ramganga (198 MW), Nagarjuna Sagar (770 MW), Srisailam (900 MW), Balimela (360 MW) and Hirakind (235 MW). Some of the run of river projects constructed in India are Dehar (990 MW), Bhaba (120 MW), Chibro (240 MW) and Sileru (460 MW). The installed capacity details for the storage and run of the river plants are given in Table 4.

Table 4

Storage vs. Run of the River Power Plants

Type of Development	Number of Stations	Installed Capacity
Storage	101	13238.20
Run-of-river	55	4845.90
Total		18084.10
Upto March 1992		18612.90

It would be opportune to point out that several joint Indo-Nepal hydro-power projects (500 to 1000 MW) are under investigation for near future installations. Some important ones are the following:

KOSI
PARAMESHAWAR
BHUDI-GANDAKI
DERIGHAT (14.1 MW, partly supplying Electricity to India at Muzzafarpur and Raxoul in Bihar Province)

In addition to rather large hydro-power plants, the Indian Government through public and private enterprises, UNDP and the World Bank has initiated and installed several micro-mini (50 to 1000 KW and upto 3 MW) hydro plants. There appears to be a potential of about 5000 MW (Installed 220 MW) for micro-mini hydro power plants in India.

Some of such current projects under actual construction are indicated in Table 5.

The role of hydro-power in harnessing hydrogen energy is a crucial one since it leads to cost competitive production of hydrogen. Of the two relevant routes for clean production of hydrogen i.e. hydro-power and photovoltaic electricity induced electrolysis of water, the hydrogen power appears more immediately relevant to developing countries like India.

Table 5

Micro-Mini Hydro Power Plants
Under Construction (1990-92)

Place	Present / Possible Capacity
1. Sriramsagar	1500/3000 KW
2. Kakroi (completed)	100/300 KW
3. Jubal (completed)	150/150 KW
4. Manali (completed)	100/200 KW
5. Satpura (Completed)	330/990 KW
6. Barbaria	325/650 KW
7. Kendupatna	250/500 KW
8. Bilkot (Completed)	50/50 KW
9. Khet (completed)	50/100 KW
10. Naini (Completed)	50/50 KW

3. Hydrogen Energy Organisations/Institutions in India

Because of the advantages of hydrogen cited above, several countries particularly those having scant resources of petroleum such as Germany, Japan and China are engaged in intensive R and D and product development programmes aimed at making transition to hydrogen and eventually ushering in hydrogen energy as a replacement for fossil (petroleum) fuel based energy systems. Because of the critical technological aspects as well as sensitive nature of involved developments, the above cited countries should now share the various technological developments with other countries.

In order to bring in the various random R and D efforts in this area under the umbrella of a nationally coordinated effort, Dept. of Non-Conventional Energy Sources (Govt. of India) organised a workshop at Banaras Hindu University (B.H.U) Varanasi during 29-30 Jan. 1988. A coordinated programme was worked out and funded by DNES during 1988-91. An outline of this programme is enclosed (Table 6). After a midterm evaluation of the programme during 5-6 July 1990, a review workshop for assessment of the national programme and for evolving future strategy leading to the development of products/devices was organised at B.H.U. during 5-6 March 1991.

A critical assessment of the on-going projects was undertaken during the March 91 Meeting/Workshop. The DNES officials requested the Technical Advisory Committee on Hydrogen Energy (and other leading experts in the area) to grade the on-going project keeping in view the output of the R and D work, the expertise of the investigators and the facilities developed/available. The DNES also desired that the TACHE and experts based on the assessment/gradation and the potentiality in regard to the future development on viable devices/products/systems may suggest certain institutions where the DNES may set up centres for development of hydrogen energy in the country. The TACHE and the experts suggested the following universities/institutes to be the general thrust centres on hydrogen energy.

a) Banaras Hindu University (Varanasi)

b) Indian Institute of Technology (Madras)

c) Indian Institute of Technology (Delhi)

In the light of the above it is planned to locate R&D, demonstration/commercialisation centres at the above institutions. The development will be centred in the first three institutes and intimate interactions with BHEL (and other similar institutions) will be undertaken in order to carry out commercialisation of the devices/products developed at the first three centres. A break up of the work to be carried out at the three centres which may be termed as "Resource Centres" is enclosed (Table 7). A part of the efforts may also be located at other universities/institutes particularly for these areas which have potential of leading viable devices in regard to harnessing hydrogen energy.

The Technical Advisory Committee on Hydrogen Energy to Govt. of India presently consists of the following members:

1. Dr. Girjesh Govil (TIFR, Bombay - Chairman)
2. Dr. Gururaja (Adviser, DNES, New Delhi)
3. Dr. O.N. Srivastava (Coordinator, Hydrogen Energy Programme, DNES) (B.H.U., Varanasi)
4. Dr. M.P.S. Ramani (BARC, Bombay)
5. Dr. K.V.C. Rao (Hyderabad)
6. Dr. H.B. Mathur (I.I.T., New Delhi)
7. Dr. A.P. Rao (BHEL, Hyderabad)
8. Dr. A.P.B. Sinha (N.C.L., Poona)
9. Dr. A.P. Jain (N.P.L., New Delhi)
10. Dr. P.V. Ramni (Madras)
11. Dr. L.V. Venkataraman (CFTRI, Mysore)
12. Dr. N.P. Singh (DNES, New Delhi, Member Secretary)

TABLE 6

Development of Hydrogen Energy - Outline of a National Programme

PRODUCTION

i.	Bio Routes (Solar - Hydrogen) (a) Ulgal (b) Bacterial	 [BHU] [SMCRI] [OU]
ii.	Upscale of Bio Routes and System Development	[BHU] [MCI] [OU]
iii.	Photoelectrochemical / Photovolatic Photoelectrolysis by Solar Cells (Solar Hydrogen)	[IIT(M)] [BHU] [KU]
iv.	Electrolysis (SPEED)	[RDU]
v.	Photocatalytic Route (Solar Hydrogen)	[MU]
vi.	Upscale of PE/PV/PC Routes (Solar Hydrogen)	[IIT(M),BHU,MU]

STORAGE - UTILISATION

(i)	Gaseous - High Pressure [(IIT, (D)]	
(ii)	Liquid Hydrogen Microbaloon	[VSSC, NPL]
(iii)	Safety [IIT(D), BHU]	

FUTURISTIC TECHNOLOGIES
(Basic research and Development)

HYDROGEN ENERGY

ON HAND TECHNOLOGIES
(Ready for development, demonstration and exploration for commercialisation)

PRODUCTION

(i)	Electrolysis (Alkaline)	[BARC, RDU]
(ii)	Electrolysis (Off-peak power) (Super thermal, Microhydel, Wind mill)	[BARC] [BHEL] [BHU] [IIT(M)]

STORAGE-UTILISATION

(i) Solid State Storage
- (a) Hydrogen Storage materials [BHU, IIT(M), NIIFT, RU]
- (b) Hydride/Hydrogen Fuel [BHU]
- (c) Hydride/Hydrogen Fueled Vehicle [BHU]
- (d) Hydride Heat Pumps[IIT(M)]
- (e) Hydrogen in Dual Fuel [IIT(D), BHU]
- (f) Hydrogen Fuel-Static Devices Gen Sets [IIT(D), BHU]

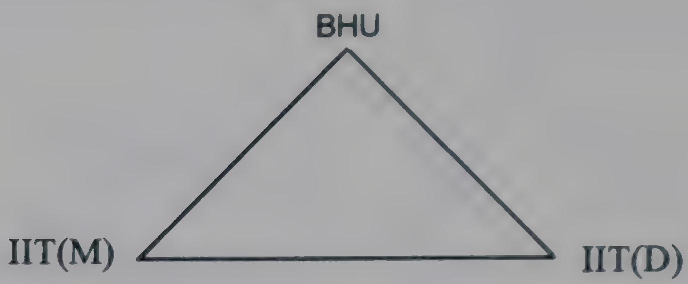
NIIFT = National Institute of Forge & Foundary Technology, BHEL = Bharat Heavy Electricals Ltd., BHU = Banaras Hindu University, IIT(D), (M) = Indian Institute of Technology Delhi, Madras MU = Madras University OU = Osmania University, RDU = Rani Durgavati University, KU = Kerala University, VSSC = Vikram Sarabhai Space Centre, NPL = National Physical Lab., BARC = Bhaba Atomic Research Centre, SMCRI = S Murugappa Chettiar Research Institute

TABLE 7

Hydrogen Energy

1991 - 1995

Resource Centres



BHU

1. Hydrogen Storage
(a) Optimisation of known Hydrogen Storage materials (eg $MmNi_{4.5}Al_{0.5}$)
(b) New HS materials
La-Mg
FeTi-x%$LaNi_5$

2. Utilisation-Product
(a) Hydride/Hydrogen vehicle
Present 20 Kms
(b) To be developed
(i) 40 to 50 Kms
(ii) 100 Kms
(With New HS materials)

3. Hydrogen Production
(a) PV Electolysis
(b) Photoelectrolysis
(New photo electrode materials/ New cell designs)
(c) Bioroutes: Genetic Eng./ (Bacterial, Ulgy) Biotechnology
(d) New Routes-:Development of Bio Reactors for HP

4. Others electricity

IIT (M)

1. Design & Thermodynamics of (Hydride) heat pump
(a) Materials Design (Operation P-T setting, Kinetic properties)
(b) Reactor modules design (Thermodynamic design Heat transfer analysis)
(c) System design (dynamic analysis, P-T profiles design)

2. Hydrogen Production PV-driven electrolysis pohotoelectrolysis New Photoelectrode materials/New cell designs (with BHU)

3. Utilisation Product
Hydride Heat Pump
(a) Airconditioner (0°-10°)
(b) Refrigerator (-10°)
(c) Freezer storage (-30°)
(d) Heat upgradation (120° to 130°C; 3 to 7 bar)

IIT (D)

1. Development of Static Hydrogen Fueled Systems
(i) Use of Hydrogen Gaseous Fuel in S.I.Engines Fueling, Firing systems, Retrofit, Flame Traps, Two parallel rigs for gasoline and H_2 operation.
(ii) Use of Hydrogen gaseous fuel in C.I. Engines Retrofit, Safety device, two rigs for diesel and dual fuel (Diesel & H_2)
2. Product Development
i. 4KW Rating SI Engine Genset (H_2 for Gasoline)
ii. 5H.P. CI Engine Genset (Duel Fuel)

Other institutions - Madras (U), RD(U), Jabal, BARC Rajasthan (U) Jaipur, SMCRI Madras (U), NIFFT

3.1 R & D AND DEMONSTRATION/COMMERCIALISATION WORK AT B.H.U RESOURCE CENTRE

a) Hydrogen Storage

The central thrust of work at B.H.U. resource centre will be on the materials aspect of hydrogen energy. In particular the central problem in the use of Hydrogen relating to the storage of hydrogen will be intensively investigated. In spite of several advantages of hydrogen over gasoline, its direct use is prohibited due to its extremely low density. It, therefore, requires special storage mode. Out of the three storage modes namely gaseous (High Pressure) hydrogen, liquid hydrogen and solid state (hydrides) hydrogen, the last option is the safest and most efficient. Amongst the three reversible hydrides namely $FeTiH_{1.73}$ and $LaNi_5H_6$, R&D efforts at B.H.U. during the last five years have been centred on $LaNi_5$ and other similar materials. In view of the indigenous availability of rare earths particularly the raw rare earth mixture (Mischmetal) in monazite ore (mostly in Kerala), attention has been centred on the synthesis, characterisation, hydrogenation behaviour and application of $MnNi_5H_{5-6}$ and $Mm'Ni_{4.5}Al_{0.5}H_6$ (Mm' = Modified Mischmetal). Capability of synthesis of this material upto kilograms of this material have been supplied to IIT (M), MU and IIT (D).

A novel application of the $MmNi_{4.5}Al_{0.5}H_{5-6}$ material synthesised at BHU has been in the development and running of hydride/hydrogen fuelled 4 stroke, 100 c.c., 1 HP, motorcycle. Thus the capability of hydrogen to completely replace gasoline has been demonstrated. This development has been noted at the national as well as international scene. For example Dr. Peter Hoffmann, the noted U.S. energy analyst, has called it as 'the first development of its type in the World' (The Hydrogen Letter 1987). Similarly Dr. H.R. Hinds (Editor International Journal of Hydrogen Energy) has termed it as a very opportune development on the Indian renewable energy scene (IJHE. Jan 1988). The range of the vehicle earlier has been only a few kms, now it has been increased (March, 1991) to about 25 Kms. One of the focal points of work at B.H.U. would be on the optimisation of production of the Mm based hydrogen storage material and then employ it as hydride/hydrogen fuel to increase the range of the vehicle to 40/50 (and then 100) kms.

Even though the on-hand hydrides e.g. $MmNi_{4.5}Al_{0.5}H_{5-6}$ are viable systems, there is a weight penalty associated with them. The maximum storage capacity weight wise is about 1.5 wt%. Thus for a 100 kms. run (at 40 kms. per litre) about 25 kg. of hydride will be required. It may be mentioned that 1 kg. of hydrogen which would be contained in about 50 kgs. of the on-hand hydrides like Mm based hydride is equivalent to about 5.26 litres of gasoline. With the present day hydrides there is about 3 times weight penalty as compared to gasoline. In view of this, one of the major thrusts at B.H.U. centre would be on the development of new high hydrogen storage capacity hydrides so that the said weight penalty can be circumvented. We have recently achieved initial success in synthesising new hydrides having 50 to 90% extra storage capacity. (K. Dutta and O.N. Srivastava, IJHE 15 (1990) 341, P. Mandal, K. Dutta, K. Ramakrishna and O.N. Srivastava, J.L.C. Metals 1991). It is proposed to investigate the following materials as possible new exotic high hydrogen storage capacity materials.

a) La_2Mg_{17}, Mm_2Mg_{17}
b) $La_{2-x}Ca_xMg_{17}$
c) $La_{2-x}Ca_xMg_{17-y}Ni_y$
d) Mg-x wt% $LaNi_5$ ($MmNi_5$)
e) Mg-x wt% FeTi(mn)

Other aspects relating to the development of hydrogen storage materials and its use for exploring hydrogen the new renewable, pollution free and indigenous fuel, as a substitute for gasoline are listed in the following:

i) Reconditioning of Multicycled Hydrogen Storage Materials.

ii) Investigation of Novel Hydrides (Amorphous, Quasicrystalline and Liquid).

iii) Further Developments on hydrogen (hydride fielded vehicles).

b) Hydrogen Production (Solar Hydrogen) Photovoltaic Photoelectro Chemical and Bioroutes

Another area where R&D and possible demonstration efforts would be carried out at BHU centre would be on production of solar hydrogen. The first route to be followed would be photovoltaic photoelectrochemical electrolysis. Particular emphasis will be paid on the optimization of new photoelectrode materials such as TiO_2-In_2O_3 which can lead to production of solar hydrogen at viable efficiencies and without the perennial problem of photoelectrode corrosion. In addition to the development of new photoelectrodes, investigation would also centre on the new cell designs e.g. the Bipolar and Semiconductor Septum PEC solar cells leading to solar hydrogen through photoelectrolysis. In accordance with the decision taken by TACHE (DNES) during March 5-6 meeting (1991) the work on photovoltaic/photoelectrochemical route of solar hydrogen production will be taken in collaboration with I.I.T. (M) centre where similar work employing coordination compound semiconductor photoelectrodes will be carried out.

Yet another potential but less explored route of solar hydrogen is the 'Bio-Routes'. The B.H.U. centre is already engaged in intensive studies in the area of bio-routes. Both the blue green algae and bacterial routes will be studied in the proposed investigation.

Particular attention would be paid in regard to the following:

- Hydrogenase - containing eukaryotic green algae.
- Cell-free chloroplast systems supplemented with bacterial hydrogenase
- Blue-Green algae (cyanabacteria)
- Growth and utilisation of bacterial in the raw materials (domestic, agricultural, industrial wastes for hydrogen production).

3.2 R&D Demonstration Work at I.I.T.(M) Resource Centre

a) Design and Development of Metal Hydride Heat Pumps, Heat Transformers and their Hybrides

The I.I.T. (M) centre is already involved in extensive research and development effort in the area of hydride heat pump and related devices.

Metal hydride heat pumps are found to be very promising in view of their wide operating temperature range (from - 90°C to 1200°C), and environmentally safe nature of hydrogen which acts as a working fluid. Metal hydrides are found to offer very good kinetics and very high densities (about $60*10_4$ to $120*10_4$). Recognizing the importance of the metal hydride heat pumps and heat transformers in the field of heat recovery and energy conservation, the I.I.T (M) has undertaken work to design and develop metal hydride heat pumps, heat transformers and their hybrids with vapour compression systems.

Further work on the aspects embodying the following will be carried out. The eventual aim would be on the development of hydride heat-pumps.

- To collect the thermodynamic, thermophysical and thermochemical properties of metal hydrides and to correlate them.
- To study the heat and mass transfer aspects of metal hydrides and in particular the thermal conductivity aspects of the hydride beds in order to design the heat exchangers for heat pump and heat transformer applications and to study the various possible configurations of these heat exchangers.
- To carry out the thermodynamic analysis and simulation of the hydride heat pumps, heat transformers and their hybrids.
- To optimise the overall heat pump and heat transformer systems and their hybrids taking into account the irreversibilities such as heat exchanger effectiveness, hysteresis effects etc.

The following methodology will be followed:

Step 1 Material design

Depending upon the specific applications, the temperatures involved are to be fixed. Depending upon these temperature levels and the corresponding pressures, suitable metal hydride pairs are to be selected.

Step 2: Reactor modules design

Next step is to carryout the thermodynamic design, heat and mass transfer analysis of the hydride beds.

Step 3; System design

This step includes the design of heat transfer fluid flow paths and their optimization, design of pressure-temperature profiles, design of the control systems, dynamic analysis of the system and the cycle optimization.

Based on the design, fabrication of the experimental system will be carried out and the performance of the system will be evaluated.

b) Hydrogen Production (Solar Hydrogen)

Photovoltaic - Photoelectrochemical Routes

Hydrogen production particularly solar hydrogen is at the centre of harnessing hydrogen energy. During the 5-6 March meeting of TACHE (DNES), it was decided that the two institutions B.H.U. and I.I.T (M) will together look into the production of solar hydrogen with the eventual view to develop commercial modules for hydrogen production. The I.I.T. (M) has been studying coordination compounds and oxide semiconductors as new exotic photoelectrode systems for solar hydrogen production through photoelectrochemical water splitting. These efforts will be strengthened with a view to develop viable commercial photoelectrolysis modules.

3.3 R&D and Demonstration Work at I.I.T(D) Resource Centre

The I.I.T. (D) centre has been doing work on use of hydrogen (as a substitute for gasoline - diesel) as a fuel in static devices (3-4 HP). In the proposed programme R&D and Commercial efforts would be centred on S.I. Engine end utility system (designated as A) and for CI Engine System (designated as B). Some details are given in the following:

A-1 (SI ENGINE SYSTEM)	Development, Standardisation & Experimental Optimisation of S.I. engine fuelling and firing systems, Test Procedures/Techniques Experiments/modifications/readjustments.
A-2 (SI ENGINE SYSTEM)	Fabrication Work - Retrofits: Flame Traps. Installation of two parallel Rigs for Operation with gasoline & Hydrogen respectively, Instrumentation, Portable system Development Fabrication and Installation.
B-2 (CI ENGINE SYSTEM)	Development, Standardisation and Experimental Optimisation of C.I. Engine for hydrogen substitution. Duel fuel system development. Test Procedures/Techniques. Experiments/modifications/Readjustments.
B-2 (CI ENGINE SYSTEM)	Fabrication Work - Retrofits, Safety devices, Installation of two parallel Rigs for Operation with Diesel neat and duel fuel mode of operation with hydrogen substitution respectively. Instrumentation, Portable System Development, Fabrication/Installation.
A-3 (SI ENGINE SYSTEM)	Performance and Emission Evaluation of Portable SI Engine Genset System. Developed with hydrogen fuelling & in parallel with neat gasoline operated system.

B-3
(CI ENGINE SYSTEM)

Performance and Emission Evaluation of Portable C.I. Engine System. Reduction of knock, Selection of diluents, Performance evaluation with various diluents, Optimisation of system vis-a-vis diluent used and proportion thereof. Water injection, Optimisation of injection of injection System and amount injected, Performance evaluation.

4. Other Centres

Of the other centres in India engaged in hydrogen energy R&D and demonstration efforts mention must be made of the work on electrolyzers being done at Bhaba Atomic Research Centre (BARC) Bombay and Rani Durgavati University (Jabalpur). While the former is engaged in the development of Alkaline Electrolyzers, the latter is involved in Solid Polymer Electrolyzers. In particular the work at BARC relating to indigenous development of an advanced type high amperage, high pressure electrolyzer using porous nickel electrodes for tonnage production of hydrogen is in advanced stage of development and prototype electrolysers have already been made.

5. Institutions/Organisations for Funding Hydrogen Energy Programmes in India

At present R&D and demonstration work in hydrogen energy in India is being funded by Dept. of Non-Conventional Energy Sources, Govt. of India. About one and half year back, a project on the development of hydrogen energy has been submitted to DNES for exploration of funding through UNDP. The technical committee on Hydrogen Energy (DNES) has repeatedly realised the importance of international funding in the area of hydrogen energy which is very crucial for India for resolving of economic problems for providing clean fuel to the expanding energy scenario.

THE PROSPECT OF HYDROGEN ENERGY DEVELOPMENT IN INDONESIA

Nenny Sri Utami

Abstract

Indonesia, as a developing country with relatively high economic growth rate, its consumption of commercial energy increased considerably, which for the main part of it is oil. Since this is the main export revenue, the role of oil should gradually be decreased by increasing the role of other non-oil energy resource.

This paper discusses the National Energy Policy, long term and short term planning of alternative energy resources, current situation of new and renewable energy development and the prospect of hydrogen energy utilization as a clean energy, a source of energy that does not pollute the environment and is renewable, and safe for electricity and transportation in Indonesia.

1. Introduction

Indonesia, as a developing country with a relatively high economic growth rate of approximately 7% per annum and with a population growth of around 2.1%, its consumption of commercial energy increased considerably. Due to the increase of energy consumption which for the main part of it is oil and since this is the main export revenue, the role of oil should gradually be decreased by increasing the role of other non-oil energy resource.

The share of oil in domestic energy use was 86.7% in the beginning of the Five Years Development Plan (1969-1970), and has significantly decreased to 62.6% in 1989-1990. The decrease was caused by the increasing roles of gas and coal in terms of supplies in the energy mix. The declining role of oil is likely to continue in the years to come with the increasing role of coal, natural gas and geothermal.

To meet the energy demand of the rural population at reasonable prices, it is beneficial if the villages could meet by themselves their energy requirements by producing it from renewable energy sources available in the area. The Government has taken vigorous steps to popularize the development of new and renewable energy such as solar energy, wind, biomass, biogas, microhydro power in the rural areas. Due to the limited budget, the volume of activity is relatively still small.

To meet the energy demand in the future, it should take into account the possibilities to develop the hydrogen technology as a clean energy, a source of energy that does not pollute the environment and is renewable, safe and usable for many purposes.

2. National Energy Policy

The basis of the National Energy Policy can be found in the Indonesian Constitution of 1945 and the guidelines state policy (GBHN).

Interministerial National Energy Coordinating Board (BAKOREN) has been established, with the members of Ministers and Director-Generals involved in energy matters. The scope of its work is as follows:

- To formulate the National Energy Policy;

- To formulate the energy development and implementation program;

- To coordinate institutions involved in the energy policy and program implementation

For the formulation preparation, Technical Committee on Energy Resources (PTE) was established with the members of representatives form the ministers, research institutions, public sector undertaking and other organizations connected with energy affairs.

The main target of national policy is to reduce as far as possible dependence on oil and to develop and use non-oil energy resources.

The major objectives of the energy policy of Indonesia are:

- To diversify energy sources for domestic use, decreasing the role of oil;

- To assure the availability of energy for domestic use at reasonable prices.

The policy is comprehensive and integrated, and takes into account the growing need for energy, both for export and domestic consumption, the preservation of the environment and the ability to supply energy on a long term basis.

Accordingly, the following policy measures will be taken during the planning period:

- Intensification, i.e. increasing and expanding survey, exploration and development of energy resources, conventional (oil, gas, coal, etc) or otherwise.

- Diversification, i.e., diversifying energy sources for domestic use to reduce dependence on oil, through the development and use of non-oil energy resources. Measures will also be adopted to develop non-exportable and renewable sources of energy for domestic use. Non-renewable and exportable resources would be used primarily for export to provide foreign exchange and government revenue to finance economic development. Non-commercial energy, which is still an important source for rural areas will also be developed. Solar, wind, energy, etc. will be developed and utilized if and where they are economically justifiable.

- Energy conservation to economize energy use by using energy efficiently and wisely, through:

a. Public campaign and educational programmes;

b. Identification of wasteful energy use, good house keeping and possibilities for retrofilling where feasible;

c. Regulation.

3. Plans of Alternative Energy Resources

Alternative energy resources to oil for Indonesia are classified into two main categories:

Renewable and Non-renewable Commercial Energy Resources : natural gas, coal, hydro and geothermal. The present natural gas reserve is estimated about 36 million BOE of gas; total coal reserves as of 1990 is approximately about 32.063 billion tonnes; potential of hydro-electric resources as of 1990 was estimated to be 75,624 MW and Geothermal reserves is estimated about 16,035 Mwe.

Non-commercial Renewable Energy Resources : biomass, solar, wind, microhydro, wave and peat. The opportunities to develop these resources is largely dependant on the potential availability of these resources.

In the short term planning of energy alternative, the government needs to create certain condition so that the dependence on oil will gradually be decreased without damaging the industrial growth. Industry is the major oil consuming sector in the country. To make it achievable, the role of non-oil fossil energy especially coal and natural gas needs to be increased to support the domestic energy needs, particularly industrial sector. In accordance with this effort, the role of commercial renewable energy such as geothermal and hydro has to be increased in order to meet the escalating growth of domestic energy needs. In this planning stage, the utilization of new and renewable sources of energy such as solar, wind, etc is required to develop at a qualitative basis. In this case, these new and renewable sources of energy will not be considered as an alternative conventional fossil fuels, but only as an additional source to avoid the full dependence on non-renewable sources of energy. This needs to be effectively carried out by paying more attention on the development of small-scale renewable projects.

In the long term planning, the utilization of non-oil fossil energy (coal, natural gas) will still be developed on a lower growth rate than that of the previous stage. To meet the domestic needs of energy, the utilization of geothermal and hydro will be substantially increased and given priority. The two energy sources will be expected to gradually displace oil for domestic consumption. In line with this programme, a sustainable biomass utilization for domestic usage will be developed. The biomass will also serve as an additional energy source to meet the growing domestic demand of energy. Meanwhile the utilization of other new and renewable resources such as solar, wind energy, etc. will be more intensified and developed to quantitatively support and serve energy needs of, especially the remote villages. In this way, the proposed energy system will gradually reach the new energy system which fully utilizes new and renewable energy resources which are considered as more favourable to the environment.

3. Current Situation of New and Renewable Energy Development in Indonesia

Forest biomass supply potential for Indonesia is estimated to be about 650 million mt/year in Java. It is estimated that 85% of rural households are supplying their own energy using fuelwood, and just about 12% of biomass energy is used in industrial sector. There are at least 31 units of wood gasifier and 6 units of wood heat gasifier that have been installed and evaluated. The conclusions were that heat gasifier has reached technological maturity, while power gasifier is a technology that still has to be improved. Ferrocement gasifier has been built and evaluated, with the result that this gasifier is cheaper and technologically better.

There are atleast 200 units of biogas digesters that have been installed and scattered throughout Indonesia using the animal waste with the capacity varying between 4-12 m^3 and used for cooking. In the future biogas using the human waste in the dormitories will have a good prospect.

Solar thermal energy for water heater is growing and reaching a commercial stage. The market share of water heaters is still dominated by the conventional system either electric or gas heater. Other application of solar thermal energy is for crop drying with the purpose to improve the quality of their products. The application of solar thermal energy for water pumping has become interesting both technically and economically.

Much has been done on the electric power generated by photovoltaic, especially in rural areas or remote areas. Microhydro development through active participation of local communities is being promoted and the development of local manufacturing capabilities is expected to lower investment cost in the near future. This kind of energy will have bright future in Indonesia.

Wind energy is used mainly for water lifting in salt industries and shrimp ponds aeration. Only small number of demonstration wind mills have been installed for lighting purposes for rural communities.

4. Hydrogen Energy Technologies

Hydrogen energy technology has not been developed in Indonesia, but it will have a good possibility to develop in future.

The main problem, the depletion of the earth's reserves of fossil fuels, will have to be faced at some time in the not too distant future. By the end of the next century, it is recognized that the supply of oil cannot meet demand indefinitely, and is likely to become scarce, or even used up. Coal may last longer, but it will become increasingly costly to mine.

A decision to reserve fossil fuels for use as sources of chemicals may take it desirable to turn to other sources of energy before fossil fuels are exhausted. Nuclear energy has been only partially successful because of its unexpectedly high cost, and because of worries over the dangers of accidents and the difficulty of safely disposing of nuclear waste on a time scale of thousands of years.

A solution to all these problems would be a source of energy that does not pollute the environment, and is renewable, safe and usable for all the purposes for which we now use fossil fuels. Such an energy system could be the use of hydrogen as a transportable fuels. Potential application of these technologies is for the decentralised production of electricity in cases where the transportation of hydrogen may be more efficient than the transmission of electrical power. The use of hydrogen as a fuel for aircraft, land vehicles and ships is likely to become important in the future.

4.1 Hydrogen Energy for Electricity

From 1969-70 to 1989-90 the primary energy supply for electricity generation grew significantly. In 1989-90 the electricity sector consumed 2.4 million BOE (5.1% of total National consumption of energy). The consumption in 1989-90 increased more than 25.0 fold to 61.5 million BOE (19.2% of primary energy consumption). Growth of electricity generation is due to the growth of electricity demand in the industrial sector, as well as in the household and commercial sectors.

The highest electricity consumption is in Java island, which is around 10.620 Mwh, and the electricity consumption outside Java is around 2,745,900 mwh (in 1990-91), and mostly used for industrial and household sectors.

Regarding to the hydro potential, it is estimated of 15,804 MW in Sumatra, 4,531 MW in Java, 21,611 MW in Kalimantan, 23.371 MW in Irian Jaya, 674 MW in Bali and Nusa Tenggara and 430 MW in Maluku.

Although hydro power is one of the more promising energy reserves for the future, some constraints such as the large investment cost required and the need for large reservoir areas prevent its rapid development, also hydro potential scattered outside Java will make the transmission of electrical power to Java island (the highest electricity consumption) would be very expensive.

The solution of these energy system in the future would be the use of hydrogen as a transportable fuels, which can be produced by splitting water by a variety of processes and can be used for the decentralized production of electricity. The transportation of hydrogen would be more efficient than the transmission of electrical power due to the above mentioned condition.

4.2 Hydrogen Energy for Transportation

It is no denying that in every human life transportation plays a very important role. Nearly all human needs and activities are influenced by transportation.

Up to the present time, fuel oil dominates the use of energy in transportation sector. If in the future Indonesia is to be the net importer of fuel oil, one of the impacts is that transportation cost will increase.

To anticipate various possibilities relating to provision of energy, and concerning the general policy of energy, the general directions to be followed in conducting energy policy are to give priority to the use of renewable energy to meet domestic needs in energy.

Among the transportation sector, the largest consumption (more than 68% in 1989) was in highway transportation. According to the place of departure-destination survey, 74% of goods and 92% of passengers carried among the level two regional areas were by highway transportation.

At present time, air transportation can only use fuel oil as the energy resource while other forms of energy are still far from being commercially used in air transportation.

By looking at transportation composition and the use of fuel oil, we can make the following conclusions:

a. Shortage of fuel oil supply will paralyse highway transportation as well as the well-being of the Nation itself.

b. Efforts to save the use of fuel oil or to find alternative energy will have a very significant meaning when it is applied to highway transportation without ignoring other modes of transportation.

In facing the possibility of fuel oil crisis in the future, transportation policy should be given priority in the use of alternative energy either by using the existing facilities or by changing to new facilities. Energy and living environment are becoming dominant issue in the future. The coming shortage of fuel oil should be solved by applying transportation modes that do not depend on fuel oil and at the same time they are close to the environment.

One of the possibilities to solve these transportation fuel problem is to develop the utilisation of hydrogen energy as a fuel, which is as safe as gasoline and natural gas. Although there are differences between the behaviour of hydrogen and the behaviour of other fuels, the development of a technology for the safe use of hydrogen as a fuel in industry, households and motor vehicles will not be a problem.

5. Annexures: Data related to several aspects of power generation and utilisation in Indonesia is presented in Tables 1 - 7.

Table 1	Energy consumption based on the source and the user sector
Table 2	Growth of fuel consumption in the industry, household and transportation sectors
Table 3	Growth of electricity consumption in the sectors of industry, household and transportation
Table 4	Hydropower potential in Indonesia
Table 5	Electrification in Indonesia
Table 6	Relation between mode of transportation and primary energy
Table 7	Possibility of generating electricity from different sources

Table 1
Energy Consumption (1990-1991)

Source	Industry		Sector Household		Transport		Total
	1000xBOE	%	BOE	%	BOE	%	BOE
Fuel Oil Source (%)	42943.2 (48.83)	24.07	49784.4 (82.68)	27.9	85694.8 (99.99)	48.03	178422.4
Natural Gas Source (%)	23957.1 (27.24)	99.80	39.10 (0.06)	0.16	9.00 (0.01)	0.04	24005.2
Coal Source (%)	9374.4 (10.66)	99.98	0.00 (0.00)	0.00	1.60 (0.00)	0.02	9376
LPG Source (%)	843.2 (0.9)	30.00	1967.5 (3.27)	70.00	0.00 (0.00)	0.00	2810.7
Electricity Source (%)	10826.8 (12.31)	56.25	8419.6 (13.98)	43.75	0.00 (0.00)	0.00	19246.4

Table 2

Fuel Oil Consumption (1990-1991)
(Thousand BOE)

Year	Industry	Household	Transportation	Total
1969-70	7095.4	17323.4	11840.0	36258.9
1970-71	8275.3	17624.1	12909.7	38809.0
1971-72	10005.6	19389.9	13796.3	43191.8
1972-73	13128.8	21208.3	15617.1	49954.2
1973-74	12334.3	23929.8	21292.8	57556.9
1974-75	14919.8	27683.6	23573.6	66177.0
1975-76	17012.5	31495.0	26134.8	74642.3
1976-77	21401.0	33881.9	28589.2	82872.1
1977-78	24421.2	37709.4	32645.0	94775.6
1978-79	28530.9	43258.3	36291.6	108080.8
1979-80	29481.8	46135.4	41297.8	116915.0
1980-81	33725.1	49532.8	45670.0	128927.9
1981-82	36082.8	52963.2	51771.1	140817.1
1982-83	35341.1	50405.1	52898.0	138644.2
1983-84	38535.3	47661.8	51491.4	137688.5
1984-85	36111.2	45289.2	53575.4	134975.8
1985-86	32995.2	43419.8	54043.9	130458.9
1986-87	32429.8	43478.3	58380.2	134288.3
1987-88	32294.7	43655.5	64195.5	140145.7
1989-90	34545.2	45059.5	69451.0	149055.7
1990-91	39315.0	47555.6	76666.0	163536.6
1990-91	42943.2	49786.4	85694.8	178424.4

Table 3

Electricity Consumption (1990-1991)
(Thousand BOE)

Year	Industry	Household	Transportation	Total
1969-70	393.7	733.7	0	1127.4
1970-71	446.5	819.5	0	1266.0
1971-72	499.4	1120.4	0	1619.8
1972-73	498.1	989.7	0	1487.8
1973-74	680.0	992.4	0	1672.4
1974-75	810.7	1046.4	0	1856.7
1975-76	927.3	1179.0	0	2106.3
1976-77	931.0	1289.3	0	2220.3
1977-78	1040.9	1462.2	0	2503.1
1978-79	1139.0	1743.0	0	2882.0
1979-80	1619.7	2104.6	0	3724.3
1980-81	1908.3	2966.0	0	4874.3
1981-82	2210.7	3435.9	0	5646.6
1982-83	2779.1	3725.1	0	6504.2
1983-84	4027.5	4028.0	0	8055.5
1984-85	4795.7	4308.8	0	9104.5
1985-86	5777.3	4762.9	0	10540.2
1986-87	6441.9	5290.9	0	11732.7
1987-88	7318.4	6057.2	0	13375.6
1989-90	7867.2	6814.9	0	14682.1
1990-91	9421.1	7475.3	0	16896.4
1990-91	10826.8	8419.6	0	19246.4

Table 4

Hydro Power Potential (1990-91)

Islands	Development Possibilities Energy Production (GWh)
Sumatera	23763.45
Java	9217.00
Kalimantan	21868.00
Sulawesi	8254.00
Irian Jaya	59996.00
Nusa Tenggara	329.65

Table 5

Electrification
Electric Power (1990-91)

Island/Province	Villages	Has Been Electrified Villages	%
Sumatera	22394	6331	28
Java	24601	12655	51
Kalimantan	9365	1314	14
Sulawesi	4839	1640	33
Maluku	1511	366	24
Irian Jaya	928	67	7
Bali	612	479	78
NTB	564	308	54
NTT	1723	131	7
Timor Timur	442	25	5

Table 6

Relation Between Mode of Transportation and Primary Energy

Mode of Transportation	Energy									
	Foil	Gas	Coal	ALC	FWD	HYD	NUC	WIN	SOL	ELECT
Highway	X	X		*		O			O	O
Railway	X	X	O	*	O					X
Sea	X	X	O	*		O	X	X		
Air	X	O		O		O				
Pipeline	X	X	O	*	O					X
Cabel	X	X	O	*	O					X
Conveyor Belt	X	X	O	*	O					X

Note : X : direct without difficulty
O : there is difficulty or still needs time
* : can be used directly but supply is difficult

FOIL : Fuel Oil   ALC : Alcohol   FWD : Firewood   HYD : Hydrogen
WIN : Wind   SOL : Solar   ELECT : Electricity   NUC : Nuclear

Table 7

Possibility of Generating Electricity

Fuel Oil	X
Gas	X
Coal	X
Alcohol	*
Wood	*
Hydrogen	O
Nuclear	X
Wind	O
Solar	O
Water	X
Geothermal	X
Low Tide	O
Marine Heat	O
Sea Waves	O
Biogas	O

X = Without difficulty

O = there is difficulty or still needs time

* = can be used directly but supply is difficult

HYDROGEN - FUTURE TECHNOLOGY FOR MALAYSIA

Prof. Madya Dr. Abdul Halim Shamsuddin

Abstract

Malaysia has no experience with the existing hydrogen technology. However, three potentially local applications may include the domestic combustion, aircraft transportation and space technology, and automotive combustion. Such developments are due to the clean burning and highly efficient hydrogen appliances and engines to replace the conventional fuels and to reduce the pollutant-containing emission which causes the co-called greenhouse effect. Hydrogen must be produced economically in large quantities, storing and transporting this fuel based on the present knowledge in handling natural gas. The challenges are to synthesize hydrogen from abundant renewable resources: solar energy and water and to effectively optimise the fuel storage in hydrogen vehicles. Malaysian public and policy makers should consider the benefits of hydrogen as alternative fuel and as the ultimate future fuel.

1. Introduction

The purpose of this paper is to highlight the potentials of hydrogen technology in Malaysia. Since there has been no reported work on hydrogen and its use for local purposes, this paper will deal on the need for such technology and the advantages derived from it. The idea of hydrogen technology began to conceptualise when the present combustion system posed an increasing threat to our environment.

For many decades, engines driven by fossil fuel released CO_2 to the atmosphere. The gas, along with other gases, e.g. CO, CH_4, NO_x, CFC, etc. absorb the infra-red radiation re-emitted form the earth, resulting a rise in the temperature of the earth.

If the present CO_2 emission trend prevails until the end of the next century, atmospheric temperature will increase by 5°C from the present 15°C and the CO_2 concentration by 760 ppm from 339 ppm (1). The resulting global environment damage is evaluated at US$2360 billion per year or US$460 per capita annually (2). This adverse trend and loss may be prevented by the use of fuel hydrogen which releases no pollutant CO_2 and NO_x during combustion.

The technology of hydrogen may not eventuate, in large scale, in Malaysia in the near future. The nation is now self sufficient in energy and a net exporter of oil and LNG. The coming decades will be dominated by the 9 percent growth of natural gas with reserve of 9.5 billion barrels of oil equivalent (BOE), and that of hydropower with daily potential of 550,000 BOE(3).

The formulated Fuel Energy Policy is connected with securely supplying energy through effective use of natural gas, hydropower and imported coal. This also results in tapping energy from renewable sources: biomass, solar and geothermal energy. Worldwide hydrogen technology and research, however, are more extensive than that of biomass and geothermal energy.

As an energy carrier, hydrogen may supplement solar energy in supplying electricity through transportation and storage network. Therefore a fully developed hydrogen infrastructure will yield a better renewable fuel alternative for Malaysia than other resources. Such a system will depend on the sectors which utilise hydrogen as a fuel.

The Working Committee on Energy of the National Council for Scientific Research and Development, Ministry of Science, Technology and the Environment has been given the responsibility to advice the Council on matters pertaining to Energy R&D. The Working Committee on Energy has since developed National Energy Research and Development (R&D) Strategy in support of the National Energy Policy. This strategy addresses the energy challenges and opportunities for the country with strong focus given on the Engineering and Commercialization aspects.

It has been recommended by the Committee that an Energy Centre be established by the Ministry. The Centre shall shoulder the responsibilities of coordinating issues on energy technology research, engineering, development and commercialisation, and to take the lead in the administration and management of all energy related matters.

Studies on the potential of emerging technologies such as new electricity power generation systems, e.g. fuel cell, hydrogen technology, etc. have been recommended by the Committee. The Committee will be organizing a national seminar on hydrogen energy as an initial effort to develop interest in this technology amongst universities, research institutions, government agencies and private sectors.

2.0 Existing Hydrogen Technology

Hydrogen as fuel are applicable in three sectors: 1) as appliance fuel, 2) in aviation transportation, hypersonic and aerospace technology and 3) automotive internal combustion.

2.1 Appliance Fuel (4)

The conventional flame-type burners can be modified to suit hydrogen combustion. Thus hydrogen for domestic use may include furnaces, water heaters and stoves.

A more attractive burning feature is the catalytic hydrogen combustion whose thermal reaction efficiency of 84 percent is 144 percent more efficient than the conventional natural gas flame combustion. A catalytic burner produces minimal NO_x hence requiring no vent or chimney. It creates concurrent room humidification-heating because combustion produces water vapour. This type of burner self-ignites thus requiring no standing pilot or electric ignition.

2.2 Aviation Transportation, Hypersonic and Aerospace Technology

Even though successful flights of fluid hydrogen (LH_2) aircrafts have been reported since the 1950s, unfortunately LH_2-based commercial airline has not yet substantiated. The past flight trials include NASA's B-57, USSR's TU-155, Lockheed's L-1011 freighters and Prat and Whitney's CL-400 aircrafts. Currently, a LH_2 Airbus with three possible tank configurations is being studied (5).

Countries with major space programmes have begun operations with hypersonic flights. These include NASP (National Aerospace Plane) by the USA, SANGER II programme by Germany, HOTOL (Horizontal Take-of and Landing) aircraft of Britain and advanced CONCORDE by France. Both Japan and USSR have initiated their own plans(5).

Space technology is hydrogen-fuel intensive. Coupled with another fuel liquid oxygen, LH_2 engines are being adopted by USA's space shuttle, Europe's ARIANE V, USSR's ENERGIA and Japan's H-II (5). Scientific developments in this field e.g. thermodynamics, reaction kinetics and cryotechnology, are so important that they are applicable to aviation.

Two new techniques in on-board hydrogen storage may be beneficial to airspace industry. First, the magneto-caloric effect on hydrogen liquefaction. The electronic magnetic moments of rare earth elements show parallel orientation to the magnetic field causing them. Furthermore, the temperature of these elements can be manipulated by varying the adiabatic change of the magnetic field. Thus, in an adiabatic demagnetization, the resultant elements temperature will decrease. The achieved temperature can be very low such that the fuel liquefaction efficiency may be improved.

Second, the hydrogen slush fuel is a mixture of hydrogen liquid and hydrogen ice. By lowering hydrogen vapour pressure to its triple point, the vapour crystallise, and subsequent slight increase above this point causes the ice to detach from the tank well and sink to the floor. Physically, 15 to 20 percent denser than liquid hydrogen and slush contributes to smaller storage size (6).

2.3 Automotive Internal Combustion

Hydrogen engine combustion in vehicles have received the widest attention than that of domestic and airspace applications. This, appropriately, is because of the absence of CO_2 and NO_x which pollute the air. There are two good techniques regarding hydrogen combustion, as described below:

2.3.1 Exhaust gas Recirculation (EGR)

This mechanism uses unthrottled hydrogen engine, an engine that operates without the control of hydrogen and air mixture. The efficiency of an engine is obtained at an equivalence ratio (ER) defined as the ideal air/fuel ratio divided by the actual air/fuel ratio.

Maximum brake thermal efficiency of an unthrottled hydrogen is at ER 0.4 while of gasoline engine at ER 0.9. This means that at ER 0.4, hydrogen engine has lower combustion temperature than that of gasoline, leading to higher brake thermal efficiency and lower emission of NO_x.

2.3.2 Fuel Induction Technique (FIT) or Hydrogen Induction Technique (HIT) (7,8)

The engine power or volumetric heating value of air and hydrogen mixture is directly related to the engine pressure but inversely related to its temperature. Therefore, FIT e.g. late injection of pressurized cryogenic (ultracold; i.e. -235°C) LH_2 will result in greater power output. In addition, it eliminates pre-ignition and backfiring because delayed fuel injection after air intake helps to cool down the 'hot spots'. This mechanism also releases minimal NO_x.

On-board hydrogen requires unconventional storage. The most effective form is by means of metal hydrides where at high pressure, hydrogen is bonded with certain metal and later is released gaseously when heat is added (9). Common hydrides include TIFe, $LaNi_5$ and Mg_2Ni stored in tightly bundled, long, thin and hollow cylinder. Metal hydrides contains high energy density and requires low temperature to dislocate hydrogen.

Another storage mode is using ultracold liquid hydrogen. At -235°C and 200 kPa, the fuel is deposited in double walled super insulated vessel which has been designed to reduce heat transfer and liquid boil-off. Storage in this form, however, is bulkier and heavier than conventional gasoline tank, on an equal energy basis, the cryogenic storage system is 10 kg heavier and 6 to 8 times larger than a gasoline tank (9).

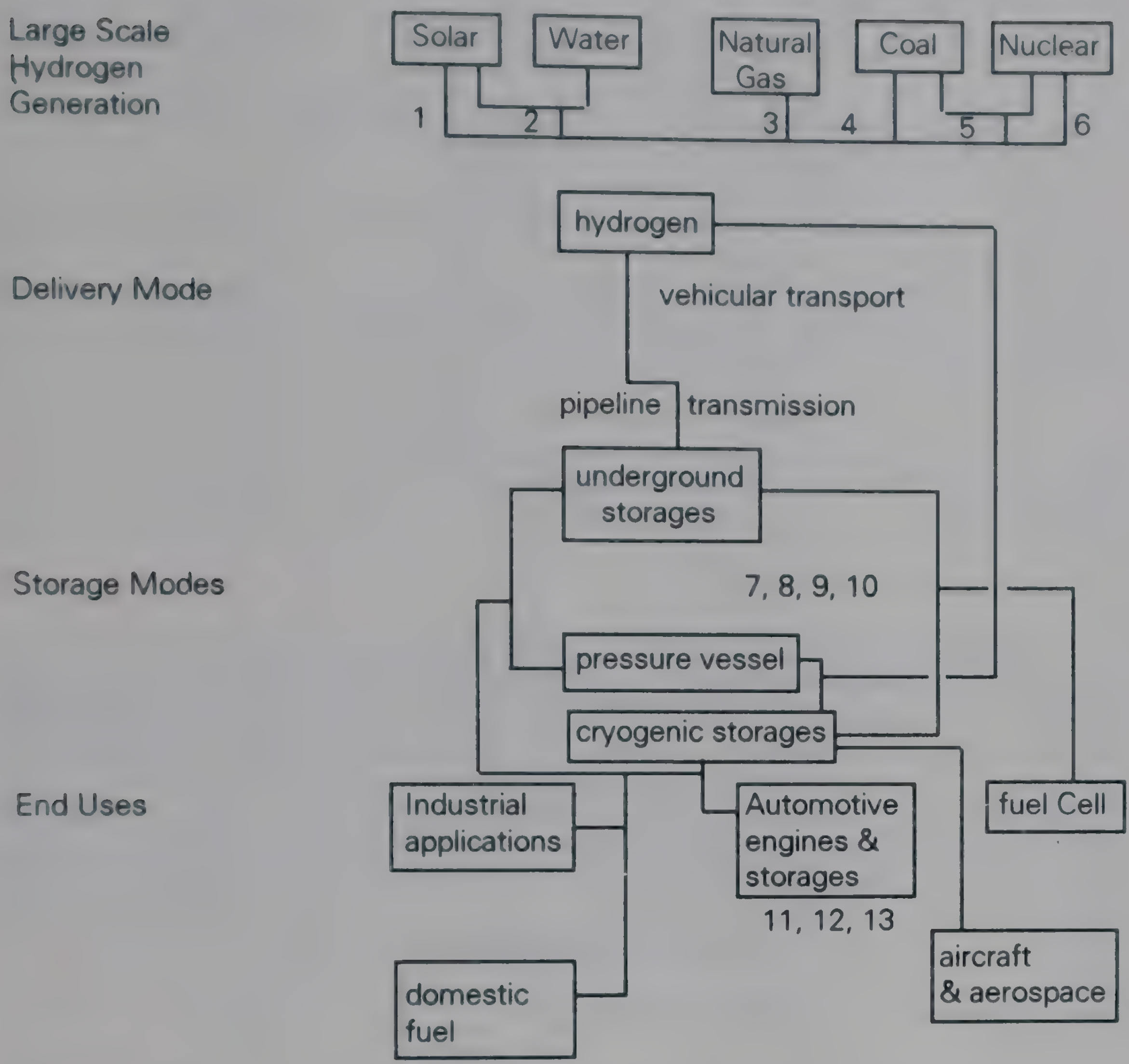
The least attractive option is to compress gaseous hydrogen. The conventional compression pressure results in too large storage since, compared to natural gas, hydrogen is 8 times less dense. In increasing this pressure to 7000 kPa, the storage tank material will be too costly (9).

3.0 Infrastructure of Hydrogen Economy

Hydrogen technology aims to provide the society with an alternative fuel. When the supply of oil, gas and coal has ceased, hydrogen and electricity are anticipated to begin an age with superior technology. Until then, the advancement of fuel hydrogen centralises on the question of economy. As Hydrogen Economy is a global endeavour, Malaysia's strive for this may lead to a nation with a system shown in Figure 1 (10).

Under the economy, there will be aspects like economically producing hydrogen, transportation of hydrogen and storaging high volume of the fuel.

Fig. Hydrogen Energy Economy



Legend :

Methods :

1. Photoelectrolysis
2. Liq./Solid Electrolyte Electrolysis
3. Steam Reforming
4. Gasification
5. Nuclear-assisted
6. Electrolysis

Modes :

7. Depleted Oil/gas Reservoirs
8. Aquifers
9. Excavated Rock Cavern
10. Solution Mined Salt Cavern
    11. Metal Hydrides
    12. Cryogemnic Hydrogen
    13. Compressed Hydrogen

3.1 Economical Production of Hydrogen

Hydrogen energy is a secondary energy. It has to be manufactured from primary resources e.g. coal, natural gas, nuclear, solar and water. The selection of hydrogen synthesis is often dictated by cost-effect viability. At present, this criterion favours the conventional methods of producing hydrogen because of high production efficiency, ample feedstock (coal, hydrocarbons) supply and low cost. Such methods include steam reforming of hydrocarbons, coal gasification and water electrolysis.

More advanced methods exist which often being the improvement of the conventional types. When large volume of nuclear heat is available, coal gasification will be nuclear-assisted (11). Further, instead of operating water electrolysis using liquid electrolyte, solid electrolyte is also possible, e.g. the high (800° to 1000°C) steam-acquired Hot Elly which used doped ZrO_2-Y_2O_3 electrolyte to conduct the oxygens (12).

One future technique is based on solar technology. Known as photoelectrolysis, it is a decomposition of water molecules in a cell made of n-TiO_2/O_2, H_2O and H^+, H_2O/Pt system. The system uses solar energy by means of solid state solar cells to release hydrogen (13).

3.2 Transportation of Hydrogen

Hydrogen is not only a secondary energy, it is also an energy carrier. This means that it can be transported and stored. The technology of delivery and storage gases is new but already being developed in Malaysia e.g. the Peninsular Gas Utilisation Projects, which involve natural gas. Worldwide experience in transporting hydrogen is minimal but the achievements are commendable. Since 1940, Germany's Ruhrkohle has been supplying 3 billion m^3 of hydrogen gas annually for ammonia production and as chemical feedstock. The pipeline reticulation has 1600 kPa nominal pressure with a total length of 220 km (14,15). Another example: ultra pure hydrogen gas has been reticulated for ten years through 5 cm diameter 41,300 IPa pressure line covering 1.6 km in the Kennedy Space Centre, USA (15). Both operations have excellent safety records.

3.3. Storage of Large Volume of Hydrogen

Similar to vehicular storage, some approaches may be used for large quantities of hydrogen. Hydrogen can be stored in pressure vessels, underground or cryogenic liquid storage (6).

At high pressure, a 14,000 m^3 seamless steel tube vessel may be used to store hydrogen. The tube is modular thus scaling-up for estimating capital costs is not necessary. This vessel may also be hauled by road trailers.

Underground gas storages include depleted oil or gas fields, aquifers, excavated rock caverns, and solution mined-salt caverns, all of which have been used to store natural gas. Large volume of gas is possible i.e. 10^9 m^3 with pressure as high as 4060 kPa. The capital cost for underground storage is high. This is because the gaseous storage consists of an active gas and cushion gas. Active gas is used as feed stock while cushion gas is the gas used to estimate reservoir pressure to define the storage volume; the latter takes as much as 50 percent of the total volume.

Gaz de France in Beynes had stored 330 million m^3 of town gas, 50 percent of which was hydrogen, from 1957 to 1974, in an aquifer. In Teeside, England, ICI filled three brine-compensated salt caverns located 366 m underground with hydrogen at 5000 kPa for an industrial complex.

At a very low temperature i.e. -253°C, liquid hydrogen has to be stored in a spherical tank. This is because a cryogenic cylindrical tank, whose exposed surface area of liquid is higher, induces greater rate of boil-off. Usually designed for space programmes, NASA's doubled walled vacuum insulated tanks have a 22 m diameter each storing 3800 m^3 liquid hydrogen.

Five conceptual hydrogen storage scenarios have been proposed (16). Each mode of storage is concerned on a specific use of hydrogen in large quantities. Option 3, for instance, refers to the conversion of tidal energy into electric energy by means of heating the compressed air using stored hydrogen.

No comparison, however, should be made between the scenarios because one does not have many choices to choose from in real practice.

4.0 The Challenges of Hydrogen Technology

The proposed future technologies have not yet matured. It is, however, believed that they are completely developed but lack of refinement and perfection. Refinement and perfection can only be derived from continuous research efforts in finding better materials, low cost production, higher efficiency and so forth.

Studies have been initiated to increase the catalyst life time used for appliance fuel; in addition, to achieve higher than 84 per cent thermal efficiency, superior appliance model is being investigated (4).

LH_2 hypersonic airplanes require the following (5):

i) combination of combustion engines that are operable from the subsonic to the hypersonic regimes;

ii) optimisation on the cryotemperature tank (-253°C), the lightweight frame structures and the craft payload, all of which can only take a few percent of the total weight.

iii) materials and structures so designed to adopt on hydrogen environment; and

iv) new and safe hydrogen network on the ground.

Storing of hydrogen in a vehicle remains a problem. Even though magnesium (Mg) and Vanadium (V) are better metal hydrides - for 100 g metal, Mg absorbs 7.6 g hydrogen while V absorbs 5.9 g hydrogen - they pose some difficulties. Mg requires higher heat of dissociation than can be provided by exhaust gas; V is an expensive rare earth metal.

Purity of hydrogen required for absorption is extremely high or the contaminated hydrides have short operating cycles, e.g. 99.999 percent pure hydrogen is required for FeTi hydride to reach 4000 cycles (17). The complete storage units - the hydrides housing and coolant system - are large i.e. 100 to 300 litres and heavy i.e. 120 to 485 kg (9). Thus the pursuit of an ideal hydride and a compact fuel arrangement characterise the direction of on-going work in hydrogen vehicles.

Other vehicular storage options that require in-depth attention include the light-weight activated carbon cryoabsorption, high pressure low-cost glass microspheres and methylcyclohexane liquid hydride (9).

Glass microspheres, for instance, can store hydrogen by carefully manipulating the transfer of the gas through selected glass at a certain temperature and pressure.

Non-fossil economical hydrogen productions are essentially laboratory-scale developments. Direct thermal water decomposition into hydrogen and oxygen can only be achieved at 2230°C for which current technology does not exist.

Breakthroughs have been reported by combining solar energy and water to generate hydrogen and electricity. This photochemical means has given rise to two cells: the Kainthla cell with conversion efficiency of 8.2 per cent and the Murphy cell with conversion efficiency of 9 percent (18). Other means include radiolytic dissociation of water and photoreduction of CO_2 (18).

High pressure steel pipelines suffer from metal embrittlement which leads to gas leakage. The actual mechanism causing this is unknown but surface conditions of pipes, e.g. impurities, micro-structural defects and oxide-surface films have contributed to the interaction between steel and hydrogen (15). Costly solutions have been proposed: coating of pipe with aluminium and copper alloy, in addition to suing precise manufacturing techniques, but such treatments are beyond that required by normal gas pipelines (15).

Hydrogen economy is about production of hydrogen. The end use of transmitted hydrogen through pipelines may require electricity for heating, lighting, etc; thus the conversion of hydrogen to electricity is necessary. This conversion can be achieved by fuel cells which use hydrogen as fuel and an electrolyte.

Work has been done to use a super acid as electrolyte replacing the already excellent phosphoric acid in fuel cells (18). Phosphoric acid, being molecular, is easily absorbed by the cell electrode in reducing oxygen but ionic trifluoromethan sulphonic acid 10 to 100 percent less absorbable hence more sites for oxygen reduction and increasing cells efficiency.

The moment Malaysia enters its Hydrogen Era depend on how, at present, it views and values the Hydrogen Economy. The country's abundant gas reserves can last for another 100 years (19). With current production rate, the remaining oil reserves are estimated at 2.3 billion barrels for a life of 20 years (20). Due to its increasing scarcity coal will be consumed at four times greater than the present rate and its worldwide supply will cease in 10 years (18).

If rigorous work is being done to commercialise hydrogen vehicles, the first production will be within 30 years or less (9). Similarly, if the development of LH_2 aircrafts starts in the coming decade, the first airplane will be in 2010 or 2020 (5). Therefore efforts to diversify energy should consider hydrogen not only as an alternative fuel for the coming decades but eventually as the future's foremost fuel.

5. Conclusion

Malaysian public may be sceptical to accept hydrogen as fuel due to past tragedies of the Hindenburg aircraft, the Hydrogen bomb and the Challenger. The common belief will be the hazards it presents to the users. However, technology now ensures safety as a priority; the fear may be abandoned through education and safety programmes relating to handling of hydrogen. Malaysia's Hydrogen Age may thus be within reach.

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PROSPECTS OF HYDROGEN TECHNOLOGY IN PAKISTAN

S.N. Sarwar

1. Introduction

Hydrogen, the smallest member of element family is available in abundance in association with oxygen in the form of water. Hydrogen is also an inherent part of fossil fuel together with carbon to form hydrocarbon. Hydrogen as a fuel is an ideal source of energy since it burns to librate water. Being in such an ideal situation from environmentally attractive point of view, unfortunately hydrogen's availability in commercial quantities is a challenge to mankind, in terms of manufacture, storage and distribution. Although significant R&D has been carried out on use of hydrogen as a source of energy in developed countries, due to technology limitation not much head way is made in developing nations.

This paper reviews activity of Hydrocarbon Development Institute of Pakistan (HDIP): nature of R&D work done in Pakistan for clean fuel technology in transport, hydrogen manufacturing technologies, case studies on utilization of Hydrogen in developed countries, R&D proposal for carrying out R&D work in Hydrogen manufacturing and utilization technology.

Paper concludes that at this juncture, hydrogen could only be considered as an alternative fuel for environmental cleanliness reasons, because the technology that is available for storage of liquid or gaseous hydrogen cannot compete on economic ground. However, in view of global awareness on environment, all alternate possibilities must be evaluated to keep this planet a breathable place for which hydrogen can contribute as zero emission fuel as far as nondesirable gases such as oxides of sulphur, carbon and lead are concerned.

As a medium of energy storage, hydrogen could be used to store waste energy from hydro electricity or any other sources.

2. A Brief on Hydrocarbon Development Institute, Pakistan

The Hydrocarbon Development Institute of Pakistan (HDIP) is a national petroleum Research & Development (R&D) organization. Established in 1975, the organization has now earned itself a pioneering role in oil and natural gas resource exploitation and use. It carries out research, maintains laboratories and acts as the technical advisory body to the Ministry of Petroleum and Natural Resources on matters referred to it.

2.1 Technical Activities

The Institute covers a wide spectrum of petroleum development including exploration, refining, marketing, utilization, transfer and development of technology and end-use control. It has a network of modern and sophisticated laboratories and related facilities providing latest know-how in areas of Petroleum Geology, Geochemistry, Biotechnology, Crude Oil Evaluation, Petroleum Products Testing, Combustion Engineering, Interfuel Substitution, Pilot Plant Studies, etc.

The HDIP Labs are the sole authority for testing and evaluation of crude oils and petroleum products in relation to prescribed specifications and standards. The Institute is also responsible for reviewing these specifications from time to time. Research efforts of HDIP in petroleum exploration are opening new avenues of scientific advancements for promoting and prompting exploration in under-explored areas. A modest computerized data base has been established for energy analysis and planning. The use of Compressed Natural Gas (CNG) in road transport replacing the conventional liquid fuel has been demonstrated as an alternative energy solution.

The end users of the research and development activities of the Institute thus include:

- Federal government
- Provincial and local governments
- Oil & gas exploration and production companies
- Petroleum refining companies
- Lube oil blenders and reclaimers
- Oil marketing companies
- Gas transmission and distribution companies
- Public transport companies and private vehicle owners
- Bulk users of petroleum products
- Industrial and commercial users of oil and gas

2.2 HDIP Project on Clean Road Transport Fuel

In Pakistan, road transport fuel consumption is increasing at 6 to 7% each year consequently and tail pipe emission is also increasing in proportionate amount. Tables 1 and 2 indicate road transport fuel consumption and emissions in 1991 along with anticipated increase in the year 2000. The local ozone forming tendencies form different are indicated in Figure 1. It was from environmental and security of supply consideration use of Compressed Natural Gas (CNG), experiences on pilot scale in Pakistan.

After many years of successful pilot scale run of this project Government has now decided to commercialize use of CNG as transport fuel through public and private companies dealing in oil and gas.

2.2.1 Hydrogen Manufacturing Process

The principal commercial processes for hydrogen manufacturing are catalytic steam reforming, partial oxidation of petroleum residue, coal gasification and water electrolysis.

The cost to manufacture of hydrogen increases as we proceed from gaseous to liquid and solid fuels, the cost of electrolysis of water is similar to methane reforming in small plants. In case of larger plants electrolysis cost exceeds significantly as economics of scale do not apply.

2.2.2 Hydrogen Manufacture in Pakistan

In Pakistan, most of the hydrogen is produced from stream reforming of methane and mainly used for hydrogenation of vegetable and lubricating oils.

In the petroleum sector a large hydrogen generation unit is planned to produce 45,000 tons of hydrogen per year at a capital outlay of US$ 54 million. In view of increased awareness of sulphur content of petroleum fuel in future more hydrogen generation units are expected to be installed for desulphurization of petroleum fuels, even though use of hydrogen is decreasing in vegetable oil industry due to health considerations.

In Pakistan, hydrogen as a source of energy has not yet become a candidate because it is capital intensive to produce, and is not yet become cost effective on commercial grounds.

3. Use of Hydrogen in Developed Countries

In developed countries legislative measures towards tail of pipe restriction in automobiles and exhaust from chimney's from industry is compelling original equipment manufacture of automobiles and industrialists to look for alternate clean fuels. The State of California in the United States has taken a lead in this direction.

In the US, if a factory is emitting pollution and it is not able to reduce it on technical justifiable reasons then the owner has to compensate this pollution by using alternate clean fuel in other area of use. For example, he or she may have to use natural gas in automobiles. In the following paragraphs, we give some on-going R&D projects in developed countries.

3.1. Arizona Cities Hydrogen Fleet Project

According to the American Hydrogen Association (AHA), consortium of Arizona cities may develop plans to implement the largest fleet of hydrogen fuelled vehicles in the world.

AHA reports that D. Baxter, Manager of fleet vehicles for the city of Tempe, Arizona and Chairman of the Rocky Mountain Fleet Association has been instrumental in developing plants for a fleet vehicle hydrogen demonstration project in cooperation with officials in Phoenix, Scottsdale, Mesa and Glendale, Arizona.

Phase I of the project would involve converting 25 fleet vehicles to hydrogen operation with advanced fuel storage and injection technology. Phase I is scheduled to last 2 years and cost about US$3 million.

The project is planned to include an advanced carbon storage technology as well as research to determine the most cost effective methods of extracting hydrogen from biomass resources such as sewage sludge, paper and other wastes.

Initially, however, the hydrogen for the fleet vehicles will be generated during day time with a solar print-focus concentrator sterling engine electrical generator set. At night and on weekends, off-peak electricity will be used by the electrolyzers. Assuming off-peak electricity will cost about US$ 0.03 to 0.04 per kilowatt-hour, the cost of the hydrogen produced is expected to be in the US$1.00 to US$1.40 per gallon range.

The fleet will also be used to demonstrate the value of fuel cell electric vehicle as well as renewable energy resources.

3.2 Liquid Hydrogen Filling Station

The Hydrogen Letter reports that the first test runs of a liquid hydrogen refuelling facility began in the early June 1991 at a prototype solar hydrogen plant in Bavaria, Germany.

The experimental facility, designed and built by Linde AG of Germany, has a 3,000 litre storage tank and is intended for refuelling BMW sedans equipped with 120 litre liquid hydrogen tanks.

A progress report on the project was given by A. Szyszka, Solar-wasserstoff-Bayern (SWB), Project Manager, at the Achema Hydrogen Symposium held in Frankfurt, Germany in June, last year.

At present, refuelling with liquid hydrogen takes about 10 minutes if all components of the fuel system are at cryogenically compatible temperatures. However, if the hoses and pipes are at ambient temperatures, they have to be cooled, purged and rewarmed after the refuelling process has been completed. This procedure takes about an hour.

According to Szyszka, the goal of the project is to design an automated system that will be "user-friendly" refuelling without special procedure in 10 minutes or less.

In the meantime, German car maker BMW continues to make progress toward a practical hydrogen car. Toward that effort, BMW has temporarily assigned one of its research engineers to the SWB solar hydrogen plant to help develop a practical hydrogen refuelling system.

The long-term goal is a robotic refuelling system where the driver parks the car in a precise position, checked by sensors and a video system. The driver opens the fuel tank lid from inside the car and from then on everything is done automatically. The fully automatic refuelling system could be achieved by the end of this decade, according to BMW engineers.

The company hopes to develop an efficient coupling device integrated inside the tank by about 1994. This would eliminate the cooling, purging and rewarming currently necessary at ambient temperatures.

BMW officials hope to be able to turn hydrogen cars over to a few average drivers in about five years, following by small test fleets of hydrogen powered cars.

3.3 Magnetic Liquefaction of Hydrogen

Magnetic liquefaction could become an important tool to substantially lower the cost of liquid hydrogen, according to participants at a 1-day workshop held in conjunction with the 18th International Congress of Refrigeration. The symposium on magnetic refrigeration and conventional liquefaction techniques was held in 1 August 1991.

Lowering the cost of liquid hydrogen would have significant implications for its use as a transportation fuel.

3.4 Progress in Hydrogen as Vehicular Fuel

The German Aerospace Research Establishment (DLR) has been involved in automotive applications for liquid hydrogen since 1979. Research and development in the area of liquid hydrogen refuelling have been part of this on-going effort.

A discussion of liquid hydrogen refuelling equipment development by DLR is provided in paper by W. Peschka and was presented at the Conference on Engine and the Environment 1991.

Fully automated refuelling equipment developed by DLR can be used and handled safely by non experts. Program contolvia microprocessors make the system fail-safe, says, Peschka. The experiences gained with liquid hydrogen may also be applied to liquid natural gas (LNG). The automatic system meets the following requirements:

- The escape of liquid hydrogen into the air is prevented.

- The refuelling process is interrupted automatically if a failure in the electronic system or the hydrogen carrying lines occurs.

- Refuelling is stopped automatically when the fuel tank is full.
- It is possible to stop refuelling by external command.

- Hydrogen-carrying lines and valves are protected against infiltration of air and humidity.

- Engine starting is prevented automatically as long as there is a connection between the car and the hydrogen station.

- It is not possible to disconnect the vehicle from the hydrogen station as long as the filling continues.

4. Proposal for R&D Projects in the Field of Hydrogen Manufacture and Utilization

In order to get familiarized with hydrogen manufacturing and utilization technology, following four projects are recommended for consideration:

1. Use of hydrogen in automobile in urban transport.

2. Production of hydrogen in pilot scale by electrolysis technique.

3. Production of hydrogen on pilot scale by steam reforming technique.

4. Use of hydrogen as domestic fuel

These are soft technology projects and if sponsored in developing countries, adoption of hydrogen utilization technology would be easily done in the region.

5. Project Proposal

A) Project Title

Use of Hydrogen in Automobile in Urban Transport

Objective

The objective of this project is to standardise use of hydrogen in transport by adequately selecting storage tanks, automobile conversion kits and hydrogen filling facilities in urban area in any country in Asia or the Pacific region.

Likely Benefits

Use of hydrogen is an environmentally attractive proposition. Countries of Asia and the Pacific region where hydro electricity or any other form of energy is cheaply available could use hydrogen as a medium of energy storage.

In many cities of Asia and the Pacific, air quality is deteriorating in urban areas. Use of hydrogen in such cities would be very helpful in improving environmental condition. In the recently held Rio de Janerio Conference on global environment, a lot of concern was shown by heads of governments on air quality. Use of hydrogen in transport would therefore, be a step towards clean air quality.

Funding of Project

UNDP/ESCAP/UNIDO may consider funding for this project.

B) Project Title

Production of Hydrogen on Pilot Scale by Steam Reforming Technique

Objective

Standardize low cost manufacturing techniques for hydrogen production in those areas where methane is available for steam reforming.

Likely Benefits

Many developing countries have small to moderately large resources of natural gas (predominantly methane). Methane produces high quality resource i.e hydrogen when reacted catalytically with steam, this process also converts some water into hydrogen along with producing hydrogen from methane.

In Pakistan, HDIP is working on process standardization through catalytically conversion techniques and can easily take up this project so as to share its knowledge with other developing countries on the subject.

Funding of Project

HDIP can take up this project however, some small assistance can be sponsored by UNDP/ESCAP or UNDP.

C) **Project Title**

Production of Hydrogen on Pilot Scale by Electrolysis Technique

Objective

Standardise low cost manufacturing technique for hydrogen production, in those areas where hydro electricity is cheaply available.

Likely Benefits

Many developing countries have small to moderately large hydro electricity potential, this source is wasted in off-peak hours. Through use of electrolysis technique, this wasted energy could be saved in the form of hydrogen. The purpose of this project is to acquire techniques in developing countries for manufacturing of hydrogen. The design data obtained from running of a pilot scale production would be scaled up for commercial scale hydrogen manufacturing plants in developing countries.

Funding Agency

UNDP/UNIDO or ESCAP may consider funding this project for developing hydrogen based energy utilizing processes for developing countries.

D) **Project Title**

Use of Hydrogen as Domestic Fuels

Objective

The objective of this project is to standardise use of hydrogen in domestic burners.

Likely Benefits

Hydrogen is a valuable source of energy storage. It burns to form water, from water hydrogen can be regenerated if a cheap source of waste energy is available. The objective of this project is to standardise home cooking burner to run on hydrogen. In Pakistan, a large industry exists for the manufacturing of gaseous fuel burner in view of availability of natural gas, this industry can readily adopt to manufacture hydrogen burners with some changes. If supply of hydrogen and expertise is made available, this project can be conducted in Pakistan so that hydrogen utilization techniques can be known in developing countries.

Funding Agency

Local agency as well as UNDP/ESCAP or UNIDO can sponsor this project.

6. Conclusion

Hydrogen is a superior quality fuel and an excellent source of energy storage medium. Its heat of combustion is more than two times that of methane on weight basis. Hydrogen storage transportation and usage is capital intensive, therefore, it is not an affordable fuel, at present. More R&D work is being carried out in developed countries, adaptive research needed to be done in Pakistan and other developing countries so that waste energy from hydroelectricity or from any other source could be tapped effectively.

In addition to project proposal presented in this paper on hydrogen manufacturing and utilization, other R&D projects such as absorption of hydrogen on a suitable medium and safety related studies may also be conducted to make this technology work in reality.

Table- I

PAKISTAN
Road Transport Fuel Consumption

		Million tonne
1991	Diesel	4.03
	Gasoline	1.07
2000	Diesel	7.0
	Gasoline	1.4

Table - II

PAKISTAN
Road Transport Fuel Emissions

1991	Carbon dioxide billions	cubic ft.	300
	Sulpher dioxide	MT	81,000
	Lead	MT	762
2000	Carbon dioxide billion	cubic ft.	492
	Sulpher dioxide	MT	140,000
	Lead	MT	1,006

AFV Ozone Forming Potential
(Relative to Gasoline)

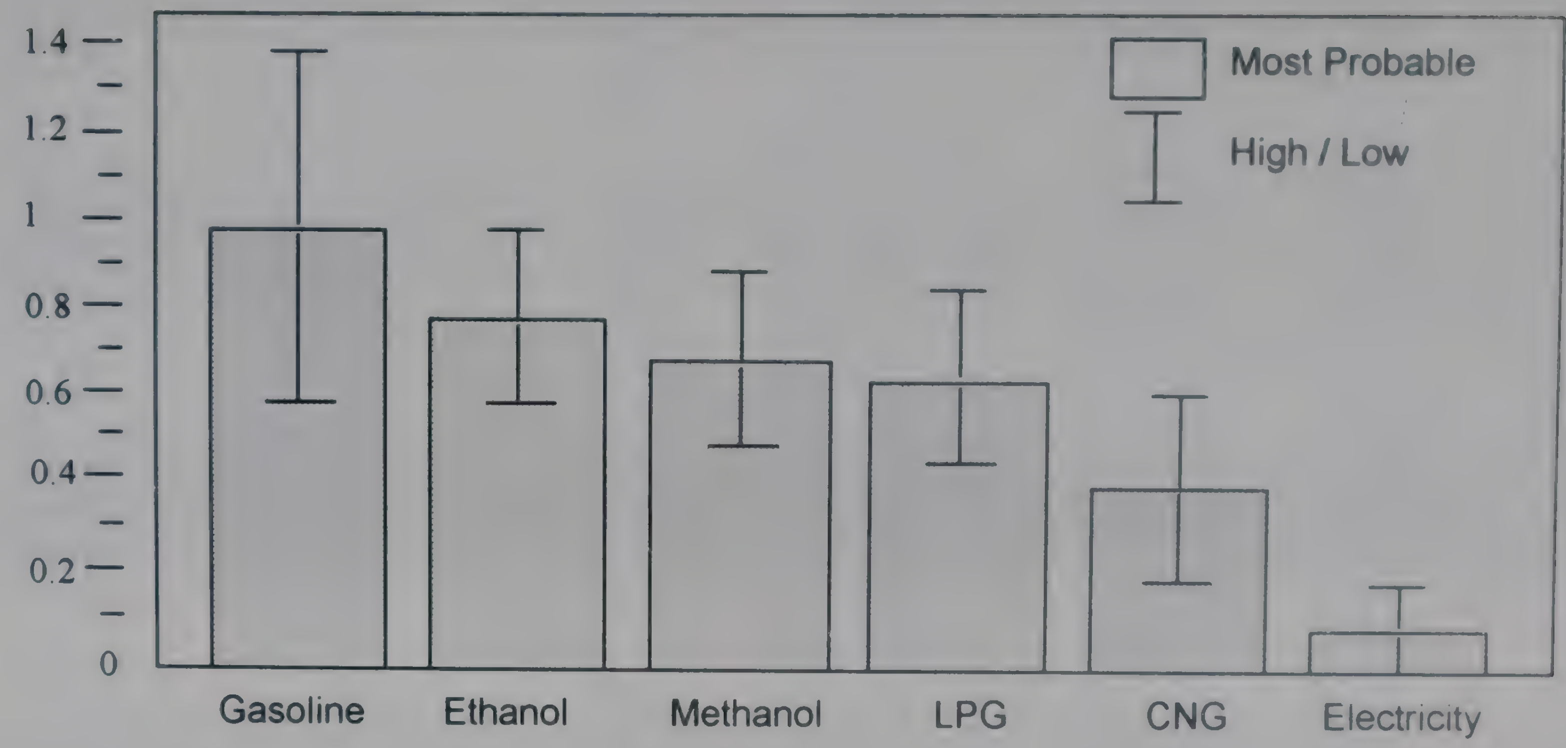

Figure - 1

USE OF HYDROGEN FUELS IN THE PHILIPPINES

Marites I Cabrera

1. Introduction

The Philippines has been and remains highly dependant on oil for its energy needs. In 1973, oil, all of which was imported, accounted for 92% of the country's energy mix. The oil import bill then was the single biggest import item and it was equivalent to 12.9% of the country's total import bill.

The government thus embarked on an energy program which targets "sustained efforts in the development of indigenous energy sources and the reduction of oil import dependence". In pursuit of these objectives, the exploration and development of indigenous resources to promote energy self-reliance has remained as the key strategy. By 1990, imported sources of energy (oil and coal) had been substantially reduced but still accounted for 65% of total energy supply.

The Philippines still has a long way to go in its program of developing indigenous energy supply to serve the needs of a growing population and a slowly recovering economy. This program has been primarily constrained by lack of capital and the softening of oil and coal prices in the international market. However, with the energy disruption caused by the recent Middle East conflict, which once again demonstrated the Philippine economy's vulnerability to external factors, it has become imperative for the Philippines to accelerate its program of energy substitution and energy conservation in order to support the country's overall economic development program.

The country has been pursuing the development of new and renewable sources of energy. However, the development of hydrogen as an alternative fuel is not an active part of its energy program. Nevertheless, the potential as a fuel in the Philippines is worth looking into.

2. The Philippine Energy Programme

2.1 Overview of Current Energy Situation

The Philippines produces and imports its energy sources. Basically, the indigenous energy sources are of two types - the conventional and non-conventional. Conventional resources consists of the domestically-produced resources such as oil, coal, hydro and geothermal energy. On the other hand, the non-conventional resources include biomass, solar, wind and microhydro.

The country's demand for imported oil and coal energy is not augmented by physically abundant indigenous resources which are in surplus. The country's energy sector has only a few operating equipments utilizing indigenous energy sources because of the lack of investment requirements for capital intensive energy projects. The demand for imported oil and coal is further ballooned by the relatively stable and lower prices of oil during the period.

2.2 National Energy Development Program

Almost two decades ago, the Philippines embarked on a comprehensive program of energy self-reliance to reduce the vulnerability of the economy to Middle East oil supply disruptions. The program aims to (a) ensure the availability of energy to the markets in the country at reasonable prices; (b) promote the judicious and efficient use of energy resources and (c) accomplish both objectives with minimal adverse effects to the environment.

As a result of efforts to develop indigenous energy resources as well as the phased departure from oil, the country has successfully reduced its dependence on imported energy from 92% in 1973 to a more manageable level of 55% in 1985. However, beginning 1986, there has been a reversal of the above trend. The import dependence was again on the rise, reaching as much as 66% in 1990, as the country took advantage of the benefits from the partial recovery of international crude prices.

Indigenous conventional energy accounted for 21% of the energy mix, while non-conventional energy accounted for about 14%. In terms of absolute contribution in volume, the shares of imported oil and coal were 63% and 2% respectively, while those for local hydro, geothermal, coal and oil were 8%, 8%, 4% and 1% respectively. Agriwaste contributed 9% while the remaining 5% come from bagasse and other non-conventional sources.

The consumption of non-conventional energy derived from bagasse, agri-industrial wastes and biomass is projected to increase modestly from an estimated level of 16.5 million barrels of fuel oil equivalent (MMBFOE) in 1992 to 23.5 MMBFOE in 2000, or at a growth rate of 4.5%. As a result, the contribution of non-conventional energy to the supply mix will decrease to 12% at the end of 2000.

In 1990, the biggest energy consumer was the industrial sector with a share of 50%, followed by the residential and commercial sectors with a combined consumption equivalent to 27%, and the transport sector with a share of 18%. The balance (5%) was consumed by other users.

The country's medium-term energy plan, anchored on sustained economic growth levels and oil price fluctuation consists of substantial efforts in fuel diversification and development of indigenous energy resources.

Total energy demand over the medium-term forecast for 1991-1995 is estimated to grow by 5.09% per annum, starting at a level of 118.1 million barrels of fuel oil equivalent (MMBFOE) in 1991. The contribution of indigenous energy share will grow from 39.18 MMBFOE to 56.45 MMBFOE in 1995 with geothermal contributing the largest share at 11.40 MMBFOE or 8.34% of the total energy supply. Hydro will account for 10.67 MMBFOE or 7.88% and coal will provide 6.19 MMBFOE or 4.48%. Agriwaste and bagasse are still expected to be the major contributors to the indigenous energy supply, accounting for about 17.4 MMBFOE or 12.83%.

To attain the objectives of the energy program, there are four major energy organisations which perform different functions. These are :

Office of Energy Affairs (OEA) - Responsible for the formulation, planning, monitoring, implementation of and coordination of policies and programs in the fields of energy.

National Power Corporation (NPC) - Responsible for power generation and trunkline transmission

National Electrification Administration (NEA) - Responsible for initiating and assisting rural distribution systems

Philippines National Oil Company - Handles energy resource development activities and provide and maintain sustainable and reliable supply of petroleum products for domestic requirement. In the past, it has also been involved in the research, development and demonstration (R&D) of renewable energy systems.

OEA acts as the central energy body but lacks the organizational mandate to carry out its coordination and decision-making functions. To strengthen and institutionalize the coordination mechanism and provide a central focus for decision-making, the Energy Coordinating Council (ECC) was created in 1988. The OEA acts as Secretariat to the EEC.

Other agencies are also involved in energy R&D in the country. Financial and technical assistance are extended by the Philippine Council for Industry and Energy Research and Development (PCIERD) of the Department of Science and Technology (DOST) to research and academic institutions through its grants-in-aid program. Continuing R&D activities on renewable are done by the Industrial Technology Development Institute (ITDI) of the Department of Science and Technology (DOST), the University of the Philippines National Engineering Center (UP-NEC), and the University of San Carlos-Water Resource Center (USC-WRC) among others.

3. Potential of New and Renewable Energy

The Philippines has an abundant supply of biomass resources such as agricultural crop residues, forest residues, animal wastes, agro-industrial wastes and aquatic biomass among others. Some of these have been considerably exploited and are now significantly contributing to the country's supply mix.

3.1 Biomass Energy

The biomass energy technologies that have showed promise for commercial applications are the direct combustion systems, gasifiers and biogas systems.

The availability of direct combustion technologies has contributed in the efficient and viable utilization of agricultural residues. A number of direct combustion systems of average efficiency levels are in the commercial status. Some applications of this technology demonstrate the generation of electrical and heat energy of several kilowatt capacities from agricultural residues such as in the ricemill industry, co-generation using coconut shell and husk, bagasse in sugar centrals, kiln drying of lumber, tobacco curing, bakeries, use of woodwaste by paper manufacturers, and use of sawdust and scrap lumber for drying of tiles in ceramics.

In mid '80s, gasifier is viable for lower priced charcoal. Today, in areas where charcoal is in short supply, the margin of profit does not justify further efforts to use charcoal gasifiers.

The technology of biogas production is now in the commercial stage. The technology is relatively well developed and several commercial level utilizations exist. The most famous is the biogas plants of Maya Farms. It is a large agro-industrial complex with animal farms integrated with meat processing plants - the first and the biggest biogas producer in the country today. The biogas provides process heat, steam and mechanical power for electricity generation.

Biogas also has common domestic uses such as for cooking, lighting, running absorption-type refrigerators and engine driven type electric generators. For industrial applications, biogas can be used in running internal combustion engines to generate mechanical or electrical power.

Although the viability of the technology has been amply demonstrated, the high initial cost, the rather complicated maintenance services required and the high corrosiveness due to hydrogen sulphide are the disadvantages that have worked against biogas systems for households.

3.2 Solar Energy

By virtue of its location, the Philippines has insolation levels suitable for solar energy applications. Several researches have been undertaken to investigate the feasibility of such applications.

Solar photovoltaic has great potential - its innovative and modular character, and the likelihood of scientific breakthroughs abroad and the local production of PV components offer substantial cost reductions. Decentralized or stand alone PV power supply systems have already been proven viable for rural electrification, drinking water systems, telecommunications, rural industries low density energy requirements and other applications which operate independently from any grid electricity supply. The commercial application of PV for rural electrification generated interest for replication in other unelectrified areas.

Solar dryers have been in use for drying grains, fruits, vegetables, fish and marine products, tobacco and lumber. There have been various designs of driers which are cheaper and great potentials exist for their mass commercial production. The OEA, however, was not able to sustain a long term promotional program for this technology primarily because of the cost ineffectiveness of promoting the technology to potential users who are mostly in small scale production and are thinly spread all over the country.

3.3 Wind Energy

Some parts of the country are also suitable for the use of windmills for water pumping and wind turbines for electricity generation. Several windmills for mechanical water pumping have been installed in the past and standard types are commercially available for a local supplier/fabricator. On the other hand, wind turbines have not been considered immediate options for electricity generation because of their poor technical performance attributed to the lack of technical competence and experience in handling wind turbine system; unavailability of spare parts in the local market; unavailability of data on wind regimes at specific sites; and high initial investment cost.

3.4 Microhydro

Microhydro is still in the development stage because of the country's very limited experience despite the presence of large hydro potentials. Micro hydro systems could supply the mechanical power of small and medium scale industries like food processing, handicraft industries, rice milling and others. There exist many competent and capable companies and even medium-sized machine shops which have the necessary facilities and expertise to fabricate or manufacture turbines, generators and other hydro power equipments. Great potentials of these systems can be viably tapped for many rural industries' energy requirements.

3.5 Priority Areas

Other non-conventional energy systems have been studied and an assessment of their techno-economic viability was done. Based on the results of pilot and demonstration projects, technologies were classified by the OEA-NCRD according to their prospects of being readily commercialized. At present, among the present priority technologies are as follows :

a. direct combustion systems for heat, steam and power generation using wood, charcoal, coconut husk/shell, ricehusk and other agriwaste;

b. photovoltaic systems for small-scale applications;

c. solar water heaters;

d. windmills for mechanical and electric generation;

e. improved stoves;

f. microhydro for electro-mechanical applications

However, the widespread utilization of such systems and resources cannot be immediately pushed due to such constraints as : (a) high initial investment cost of the system of energy conversion compared to conventional ones; (b) lack of capital; (c) lack of knowledge on the opportunities to conserve and use non-conventional resources for energy; (d) technical disadvantage of non-conventional systems compared to existing conventional systems; (e) reliability of supply and (f) socio-cultural constraints, among others.

Other technologies under the purview of the OEA-NCRD are as follows :

a. Biomass energy systems :

Biomass gasification for process heat generation, mechanical and electrical power generation

Biogas for heat, steam and electrical power generation

Alcohol fuel systems for mechanical power generation

Coconut oil fuel systems for mechanical power generation

b. **Solar energy systems :**

Solar thermal systems

- solar absorption refrigeration systems
- solar thermal power plants

Photovoltaic systems

- centralised photovoltaic power plants
- grid-intertied photovoltaic systems

c. **Ocean energy systems :**

- wave energy systems for electrical power generation
- tidal energy systems for electrical power generation
- ocean thermal energy conversion systems (OTEC) for electrical power generation

d. **Others**

- hydrogen fuel systems
- nuclear fusion power plants

4. Program on the Development of New and Renewable Energy

The OEA is mandated by law to pursue "sustained efforts" in the development of indigenous energy sources and the reduction of oil import dependence". The program seeks to meet the following fundamental objectives :

- Supply objective - to ensure the availability of energy to the markets in the country at reasonable prices
- Demand objective - to promote the judicious and efficient use of energy resources
- Environmental objective - to accomplish both objectives with minimal adverse effects to the environment

The policies for the non-conventional energy subsector are as follows :

a. Promotion of the efficient use of indigenous non-conventional energy resources

b Encouragement of local manufacture of non-conventional energy equipments and devices

c. Inducement of a favourable market environment for both buyers and sellers of non-conventional energy systems

d. Support of non-conventional energy projects which can bring socially and environmentally desirable impacts to the country, especially to the rural population.

In consonance with these policies, the CEA has established a non-conventional energy program (NEP) which seeks to develop and strongly promote the use of non-conventional (new and renewable) energy systems which are technically feasible, socially desirable and economically viable. This involves three component programs, namely :

- The Technology Program which aims to improve further the commercial competitiveness of laboratory-proven non-conventional energy systems and for maintaining such competitiveness by conducting technical research projects in cooperation with public or private research institutions.

- The Promotion and Commercialization Program which aims to accelerate the development of a market environment conducive for commercial use of a non-conventional energy and to strengthen the market by providing incentives towards a more significant participation of the private sector.

- The Affiliated Non-conventional Energy Center (ANEC) Program which aims to establish an institutional mechanism for the promotion and use of non-conventional energy in rural and remote areas using a decentralised project planning and implementation strategy by establishing ANECs at provincial universities and agricultural colleges to serve as rural extension arms of OEA.

4.1 On-going Programs and Projects

4.4.1 Overall Non-conventional Energy Program

At present, under the overall non-conventional energy program, the OEA-NCRD implements and monitors the following on-going programs and projects :

a. WB-Energy Sector Loan (Non-conventional Energy Competent)

The project is concerned with the institutionalization of methods and procedure for energy planning at regional and sub-regional levels. Several training workshops have been implemented late last year and these include the LEAP and Rural Energy Planning

Preparations for the follow-up training workshops on LEAP and SPSS + are underway. Moreover, applications of the energy model and the computer software will be undertaken by the ANECs to develop the local energy plan. The pilot testing of the National Framework on the Integrated Approach to Energy Planning for Sustainable Agriculture and Rural Development will be done in selected regions.

b. **Integrated Rural Energy Planning**

Rationalizing the energy planning approach in the country, multi-agency technical working groups were formed to develop a National Framework for an Integrated Approach to Energy Planning for Sustainable Agriculture and Rural Development through the sponsorship of the Food and Agriculture Organization of the United Nations. The general objective of the framework is to create a bridge between the energy sector authorities and those authorities dealing with agriculture and rural development through which the rural and agricultural sector plan is integrated with the energy plan. In a recent NEDA Board meeting, the framework was approved and an Executive Order will be formulated for the smooth implementation of the framework. Proposals will also be developed and submitted to potential financial institutions.

The framework was recently approved by the NEDA Board. An Executive Order will be drafted for the smooth implementation of the framework. The Memorandum of Understanding among the various agencies involved i.e. OEA, NEA, NPC, PNOC, NEDA, DA, DENR, DAR, DTI, DILG, DOST and DOTC will be signed by their respective agency heads to formally document their commitments for the success of the undertaking. Proposals containing the action plan will be prepared to be presented to potential funding institutions.

c. **Non-Conventional Energy Planning Assistance**

Funded by the WB-ESMAP, the activity is aimed at preparing and then assisting the implementation of specific strategies and actions to ensure that Philippines non-conventional energy development efforts are :

(i) prioritized and focused on those of greatest socio-economic significance;

(ii) directed toward realistic and achievable ends, given the financial, economic and infrastructure constraints;

(iii) efficient in terms of utilization of scarce budgetary and human resources; and

(iv) integral to national macroplans and development trends.

The project has two components : (i) pre-investment study on Industrial Biomass Residue Utilization; and (ii) training module on Decentralized Non-Conventional Energy Project Analysis and Appraisal. The Terms of References (TORs) for each of the activity have been prepared and initial steps are being undertaken.

4.1.2 The ANEC Program

The centrepiece program of the NEP is the affiliated Non-Conventional Energy Centre (ANEC) program. The ANECs established under this program are strategically-located universities and agricultural colleges which link the NCRD to the grassroots. Since the inception of the program, the continued establishment and management of regional ANECs have resulted in the setting up of fifteen (15) ANECs in eleven (11) regions of the country except region 11. The ANECs have successfully promoted the use and commercialization of the non-conventional energy technologies to augment the energy supply in the country side.

The major activities of the ANECs for the current year are the application of the energy model, LEAP and the computer software, SPSS+ for the development of the local energy plans. These energy plans must contain the key elements that will provide the sound basis for future actions. Items, such as growth projections, rural energy demand, energy resources accounting, strategies and action plans are the relevant contents of the plan.

4.1.3 Technology Program

The program aims to develop economically viable NESs to level of technical maturity at which NESs can fully be commercially competitive with conventional energy systems. The only projects under this program at present are as follows :

a. Philippine-German Photovoltaic Pumping Project

The project is a cooperation between the OEA, GTZ, Local Water Utilities Administration (LWUA) and the USC-WRC. It is aimed at demonstrating the technical reliability of photovoltaic pumping (PVP) systems in the rural areas and determine the conditions of their economic competitiveness. To date, several pumping tests have already been conducted on PVP sites with open well sources. At the same time, profile levelling of the five sites were done by the WRC and the water demand survey was conducted on the four sites. Future activities include the procurement and installation of equipment.

b. OEA/UP-NEC Solar Energy Laboratory

The Solar Laboratory is being maintained in order to provide technical services to OEA and other agencies, organizations and individuals who are engaged in the development and dissemination of solar energy systems, particularly, photovoltaic systems.

4.1.4 Promotion and Commercialization Program

Developing and strengthening the local non-conventional energy market are the major thrusts of the promotion and commercialization program.

The major activities included in the program are :

a. Finesse Program

The Financing of Energy Services for Small-Scale Energy End-Users (Finesse) Program was officially initiated by the World Bank's Energy Sector Management Assistance Program together with the US Department of Energy (DOE) and the Netherlands Ministry of Cooperation in August 1989. On October 1991, a regional workshop was held in Malaysia where FINESSE member countries presented their country market study report. As a result of this activity, a review of the Philippine country market was done in June 1992 by a UNDP mission. A report will be submitted to the Philippine Government which will be the basis for the formulation of project proposals to be prepared and submitted to multilateral funding donors.

b. Manpower Development Program

NCRD is currently undertaking several activities aimed at enhancing the manpower capabilities of the sector. Two big manpower development packages are being negotiated with the Dutch and German Governments. Both have five-year project duration and offer short and long-term courses on rural energy planning, biomass, solar and hydro-power technologies.

c. Information Linkages

NCRD realizes the fact that the advancement of knowledge and experience of NCRD staff in the field of non-conventional energy can be enhanced if linkages with local and foreign agencies involved in energy are developed.

Among the activities that are being done are the following :

(i) Intensification of information exchange through linkages with foreign institutions concerned with energy;

(ii) Active participation to the ASEAN Expert Group on New and Renewable Sources of Energy (NRSE), a regional working group tasked to formulate plans for the commercialization of NRSE in the ASEAN region;

(iii) Active involvement and support for the Renewable Energy Association of the Philippines (REAP), an organisation of private manufacturers and distributors of non-conventional energy equipment in the Philippines.

4.2 Support Plan (Assistance) on Renewable Energy Development and Implementation

The country's present energy policies and clearly supportive of efforts to develop and disseminate the use of renewable energy and energy conservation technologies. Policy strategies are in fact very specific about promoting energy self-sufficiency by developing use of indigenous renewable energy resources, a policy which directly translates to developing renewable energy resources since all renewable energy resources are indigenous. The concern about minimizing adverse impact to the environment in implementing and operating energy projects is another policy strategy directly supportive of the use of renewable energy technologies.

However, a close scrutiny of the country's experience in the past years indicates that inspite of existing favourable policies, many of the alternative technologies have not made significant contribution to providing the energy needs of the country. This could be attributed to the following :

- lack/inadequate incentives
- inadequate energy planning
- insufficient manpower to foster the development and promotion of the technologies
- deficient information dissemination

- market supply

- inadequate research and development

- databank on new and renewable is not readily available.

At present, a law is being proposed to strengthen the national program for the development and promotion of use of non-conventional energy systems. It stipulates that priviledges be given to local manufacturers, dealers and non-conventional energy users. Incentives include exemption from payment of tariff, custom duties and value added tax for all imported non-conventional energy machineries, equipment or devices, components and spare parts.

A very significant development in the energy sector are current efforts to adapt the concept of "An Integrated Approach to Energy Planning for Sustainable Rural Development". The objective is to develop coordination among various agencies, institutions and organisations and adapt program planning methods such that rural development, particularly the provision of the energy inputs it requires, it achieved with minimal adverse environmental impacts and in a sustainable fashion. Other activities are also being undertaken which would strengthen the capabilities of OEA-NCRD on non-conventional energy planning from technology assessment to the development of local energy plans.

In addition, OEA is proposing a five-year program to the Dutch and German Governments which aims to develop the country's capability to implement its own regular training programs. Thus the country will have its capability to produce its pool of local experts in renewable energy technologies and rural energy planning. The areas of studies include rural energy planning and development, basic principles of renewable energy systems, courses on the design and operations of biomass, solar, small hydro and wind energy systems, and energy management in small industries. Among the primary targets are staff of OEA itself, the ANECs and research institutions. Included also are other government agencies involved in rural development and energy services, private energy service firms, manufacturers and non-governmental organizations.

The research and development on alternative technologies has been continuing although on a very low-key level and the results of these researches eventually brought some of the alternative technologies to competitive levels with conventional energy systems albeit for some specific niches of applications only. In the recent past, there had been small but concrete and convincing achievements of the viability of applications of these alternative technologies for specific areas of applications yet the dissemination of their utilization have not still been significant.

Aside from the OEA, another government agency engaged in the research of energy technology is the Philippine Council for Industry and Energy Research and Development (PCIERD) of the Department of Science and Technology (DOST). Financial and technical assistance are extended by the PCIERD to research and academic institutions through its grants-in-aid program. These research activities are evaluated and chosen in terms of their impact on socio-economic development and their potential contribution to the technological advancement of the country. OEA supports research that develop and further improve the techno-economic efficiency of non-conventional energy systems to make them competitive with conventional energy systems.

Other activities in support of the non-conventional program are continually being done by the OEA-NCRD in coordination with other related agencies and institutions.

5. Potential for Hydrogen Fuel

At present, Hydrogen is locally produced from water by electrolysis and methanol separation. Unlike, the very abundant water, methanol is sourced from abroad. Hydrogen is used as a reducing agent and in converting vegetable oils to margarine. Export of hydrogen is reportedly insignificant and were reported only in 1985 and 1986. No exports for 1992 is expected. There are two local producers of hydrogen, namely Consolidated Industrial Gas, Inc. (CIGI) and Superior Gas (SUGECO).

CIGI, being the major producer, generates hydrogen from electrolysis of water and methanol-cracking process. It has an average production of 500,000 m^3 of hydrogen per year. Sales of this product is concentrated on the food industry, semi-conductor industry and power plants.

Although the development of hydrogen as an alternative fuel has been undertaken by Philippines Research Organization, the OEA-NCRD considers this a part of the energy stream which may have potential application if there are sufficient resources for research and development, pilot testing and dissemination in the country. Finding solutions to our energy problem is of utmost importance at the moment because of the acute power shortage plaguing the country particularly the Luzon and Mindanao areas. The inability to increase capacity in power generation coupled with natural calamities heightened the country's energy dilemma.

To help promote the use of hydrogen fuel as an alternative energy source, studies to determine its viability under local conditions could be done.

5.1 Study on Hydrogen Production

As mentioned before, hydrogen is already being produced locally from water and methanol. However, there is a need to determine the technical and economic viability of producing hydrogen as fuel from different processes under local conditions. For instance, the Philippines does not have sufficient generating capacity to produce electricity. However, there may be areas in the country where there is excess electricity, particularly from hydroelectric sources. This might make the process viable and there could be a demand for the fuel produced to make the venture economically and financially viable.

Mention has been made in literatures on the use of photovoltaics as a source of power for the electrolysis process. At present, we are on the fringe of commercializing the technology as a source of power for lighting and small appliances in the rural areas. We found that PV is applicable in very remote areas, particularly in the interiors and island communities which are not connected to the grid, because of the rather prohibitive cost of the system which cannot compete with the cost of conventional grid electricity.

Electrical power generation cost in the Philippines varies as follows :

Geothermal/Hydro/Thermal	-	\$0.10 to \$0.14 per KWhr
Diesel-fired plants	-	\$0.13 to \$0.38
Diesel gensets	-	\$0.43 to \$2.90
Gasoline gensets	-	\$0.57 to \$7.00
Charged batteries	-	\$1.80 to \$5.90
PV alternatives	-	\$0.50 to \$2.00

Therefore, a comparative techno-economic analysis of the various methods of hydrogen production applicable in the Philippines should be investigated.

This study could be done by the OEA-NCRD in cooperation with its Affiliated Non-conventional Energy Centre (ANEC), which will provide the data and information from the different provinces and/or regions in the country.

5.2 Study on Hydrogen Utilization

A study is proposed with the objective of developing an implementation plan for the utilization of hydrogen fuel. The study must identify specific sectors and energy-consuming groups which can shift to hydrogen fuel, like the transport and household sectors. In addition, the extent of redesigning their energy devices including costs should be identified.

This study can be initiated by the OEA-NCRD in cooperation with the Department of Science and Technology through its various research arms.

A thorough study on the feasibility of phasing-in a national program on hydrogen fuel should also be made once its financial and economic viability has been proven. The financial and economic impacts of this program would be evaluated wherein the fluctuations in petroleum prices are closely considered.

V. APPENDICES

HYDROGEN SCENARIO IN NEPAL

Rana K.N. et al.

1. Hydrogen Demand in Automotive Use

1.1 Transport Sector

Transport sector includes a wide range of infrastructure for the domestic and international movement of passenger and cargo over land, water and air using traditional and modern modes of equipment. Nepal has relatively underdeveloped transport infrastructure which mainly consist of land and air networks. The waterways remain virtually unutilized and motorized river traffic, which is generally the cheapest means of transportation, plays little role in the economy.

Among the land transportation, most of it in the nonformal sector is on foot, by cart or bicycle. The traditional foot-trails are still prominent in the hills, but they are being gradually replaced by road networks. In fact, road is the most important means of transportation in land-locked Nepal today. The minuscule railway system, 52 Kilometres in total length, has very limited economic significance. Similarly, electric traction (42 Kms of rope and 13 kms of trolley) has yet to make a real impact on transport sector of Nepal.

The total length of road networks consisting of black topped, gravelled and fair-weather roads was nearly 7,330 Kilometres in 1990. The narrow roads are mostly constructed in steep, hilly terrains which have caused major landslides and soil erosion. The quality of the road is generally poor. Besides the dilapidated road condition, which results in wastage of fuel consumption in addition to slow vehicle transportation and passenger discomfort, proper maintenance of roads as well as vehicles are lacking. The traffic density in most of the roads is low with only 200 to 600 vehicles plying per day. The average annual mileage covered by a typical truck and bus is also low. Thus road transportation cost in Nepal is rather high.

Nepal had altogether a fleet of 87,824 vehicles registered by July 1991, out of which 9.5 percent were trucks, 5.3 percent buses and mini buses, 30.3 percent cars and jeeps, 42.5 percent motorcycles and 12.4 percent assorted vehicles such as tractors, three wheelers, construction equipment etc.(1). All these vehicles are import articles just like fuels (petrol and diesel) to operate them. The demand for spare parts, which is another import component, is also very high due to the high wear and tear of vehicles in the rough Nepalese road condition.

In land-locked Nepal, air transport is next to road in importance. The country has today a network of 43 STOL, medium and international airports and serves domestic passengers to many remote areas which are not yet connected by road networks. The airline has meanwhile increased the fleet numbers and extended the service network abroad so that both passenger and cargo transport have been growing at a steady rate in the international sector.

As stated earlier, hydrogen is an excellent fuel to substitute hydrocarbon (petrol, diesel and kerosene) in automotive use. In fact, the use of liquid hydrogen has reportedly many advantages over conventional fuel in jet aircrafts. But shall discuss here the use of hydrogen in road transportation only at this stage for practical reasons.

1.2 Energy Consumption Pattern in Transport Sector

The transport sector accounted for only 1.72 percent of the total energy consumption in Nepal in 1990/91. This level of energy consumption is indeed very low and it may even appear inconsequential from the point of view of fuel substitution. But the low quantity of fossil fuels consumption in Nepal could be viewed as a blessing in disguise since it offers a better scope for the transition to new and renewable energy sources such as hydrogen than in other economies having more developed fossil fuels infrastructure, where the transition is very painful. As a latecomer, Nepal is starting from the scratch and, therefore, can avoid the costly oil structure altogether.

Nevertheless, the modern transport sector of Nepal is at present entirely dependent upon imported petroleum and coal. In fact, the imported oil has a share of almost 99 percent (Table 1). Thus the modern Nepalese transport system displays extreme vulnerability with regard to oil supply which was fully exposed by the trade and transit impasse between India and Nepal in 1989. Given this extreme reliance on imported oil, the expansion of transport networks appear very difficult in Nepal. Hence the substitution of imported fossil fuels with locally available renewable energy sources is an essential condition for the growth of transport sector in the country.

TABLE 1

Energy Consumption in Transoport Sector (1990/91)

	Fuel	Quantity (GJ)	Relative contribution (%) Domestic	Import
1.	Petroleum Fuels	4581225	-	99.88
2.	Coal & Coke	45360	-	0.98
3.	Electricity	6732	0.14	-
	Total	4633317	0.14	99.86

Source : Water and Energy Commission

The transport sector, which is also the single large consumer of oil in the country, mainly uses three types petroleum products namely, petrol (gasoline), diesel and aviation turbo fuel. If the consumption of petroleum fuels in transport sector alone will be considered, high-speed diesel oil has lion's share with 66.77 percent in 1990/91 (Table 2). Aviation turbo fuel ranks distant second (the purchase of this fuel the abroad destinations of Nepalese aircrafts is not included (Table 2) followed by petrol. Thus high speed diesel is single most important fuel for transportation in the country.

TABLE 2

Consumption of Petroleum Fuels in Transport Sector (1990/91)

	Fuel	Quantity (GJ)	Proportion (%)
1.	Petrol	791072	17.27
2.	ATF 1_/	731061	15.96
3.	HSD	3059092	66.77

Note : 1_/ As the price of aviation turbo fuel is chepaer abroad destination, the Royal Nepalese Air Corporation has been reportedly purchasing much of fuel outside Nepal (18).

The time-series import data of selected petroleum fuels presented in Table 3 which show that the consumption is growing between 5 to 10 percent per annum over the period of 1974/79-1990/1991. But the import statistics of 1989/90 and 1990/91 distorted due to the supply restriction caused by the trade transit impasse between India and Nepal. Further, the import aviation turbo fuel does not reflect the actual consumption for the reason mentioned above.

The retail prices for selected petroleum products in Kathmandu for the period 1973 to 1991 are presented in Table 4. These prices reflect the international trend in the price petroleum products as well as HMG/N pricing policy.

TABLE 3

Import of Selected Petroleum Fuels in Nepal

Import (10^3 MT)

Year	HSD	ATF	Petrol	Kerosene	LPG
1974/75	22.4	7.2	7.3	25.9	
1980/81	47.4	13.0	8.1	29.4	
1981/82	43.0	15.0	9.5	26.1	
1982/83	51.3	15.3	10.9	27.7	
1983/84	54.0	18.0	12.2	35.5	
1984/85	63.0	19.0	13.1	41.9	1.1
1985/86	66.7	17.9	14.4	48.4	1.4
1986/87	72.1	20.3	14.7	57.1	1.9
1987/88	73.3	19.7	15.6	51.8	2.3
1988/89	75.3	16.2	17.3	63.2	2.5
1989/90	85.3	7.2	10.4	72.1	-
1990/91	106.4	16.5	17.2	75.9	3.8
Average annual growth rate :					
1974/75 1990/91	10.23	5.32	5.50	6.95	
1980/81 1990/91	8.42	2.41	7.82	9.95	

Source : Nepal Oil Corporation (4)

TABLE 4

Retail Petroleum Prices - Kathmandu
(1973 - 1991)

Effective	HSD	MS	KER	Cost (Rs/Ltr) ATF	LPG(Rs/Kg)
Aug 17 1973	1.94	2.88	1.19		5.30
Nov 5 1973	2.03	4.46	1.58		5.30
Nov 11 1973	1.71	3.91	1.58		5.30
Nov 16 1973	1.71	3.91	1.35		5.30
Mar 5 1974	1.80	4.55	1.54		5.30
Jun 5 1974	1.85	4.55	1.54		5.30
Jun 18 1974	2.00	5.75	2.00		5.30
Dec 19 1975	2.00	6.00	2.00		5.30
Feb 25 1976	2.50	5.00	2.50		5.30
Jul 7 1976	2.64	6.75	2.50		5.30
Feb 5 1979	3.40	7.00	3.10		9.45
Jan 24 1980	4.60	8.30	4.25		9.45
Jul 12 1980	4.60	9.30	4.25		9.45
Nov 15 1980	5.65	9.30	5.15		9.45
Nov 1984	7.50	10.80	5.50	8.28	10.51
1986	7.50	10.80	5.50	8.28	10.51
1985/86	7.50	10.80	5.90	9.26	-
1986/87	7.50	10.80	5.90	9.71	-
1987/88	7.50	12.90	5.75	9.71	-
1988/89	7.50	12.90	5.75	9.71	
1990/91	9.10	19.00	6.90	13.26	11.62
	10.00	25.00	8.00	13.26	11.62

Source : S.P. Sharma, Energy Pricing Policies in Nepal (5) (For 1973 to 1985 period)
Nepal Oil Corporation (for 1985/86 to 1991 period (4)

1.3 Supply and Pricing Mechanism of Petroleum Products in Nepal: Economic Costs and Retail Prices of Selected Petroleum Fuels

Nepal Oil Corporation (NOC) has the overall responsibility for import, storage and distribution of all petroleum products in Nepal. As Nepal has no access to sea, oil supply in Nepal is dependent upon world oil market as well as on mutual agreement with India. NOC purchases kerosene and diesel oil in the international open market to ensure the best prices for these products under spot market conditions or long-term contract. As these products cannot be directly imported to Nepal, NOC hands them over to India which in return supplies a mix of petroleum products required by Nepal (such as motor spirit, aviation fuel, liquid petroleum gas, light diesel oil, furnace oil in addition to diesel and kerosene) as per the "Product Exchange Agreement" between Nepal and India. Nepal, however, remains susceptible to variations in refiner's cost, profit margins, administration, transportation and storage costs in India.

The total storage capacity of NOC was only 31,350 Kilolitres at 9 different sites within the country in 1991/92 and planned to instal additional 48,500 Kilolitres by 1993. As the total storage capacity of 31,350 kilolitres is to hold sufficient stock for Nepal, it has further increased Nepal's dependence upon India.

The trade and transit impasse between India and Nepal in 1989 has fully exposed the vulnerability of this arrangement for petroleum import into Nepal. But as a land-locked country, Nepal has no other option for oil import. Hence the same old agreement with India was revived in 1990. The mechanism adopted by NOC for petroleum import is as follows:

a) Lease of tankers to carry kerosene and diesel purchased on the open market to ports in India;

b) Arrangements with India for the use of Indian port, unloading facilities and bulk storage tanks;

c) Equipment of kerosene and diesel destined for Nepal by rail either to the Indian refinery in Barauni, or to the storage facilities in Raxaul at Indo-Nepalese border;

d) Transportation of required mix of petroleum products by NOC tanker trucks either from the refinery at Barauai or from the storage facility at Raxaul to the central storage facilities of NOC at Amlekhgunj in Nepal; and

e) Transportation by tanker trucks from the central storage facilities at Amlekhgunj to local distributors throughout the country.

The cost break-down of major petroleum products for March 1989 (period before supply impasse) and 1991 are shown in Tables 5 and 6 in order to compare them. Needless to say, the costs of petroleum products directly imported by Nepal during the impasse was much higher than the prices prevailing in 1989, but they can not be considered as representative costs and hence are omitted here. Licenses were granted to different private parties under OGI for petroleum products, import during the impasse. The cost of procurement (CIF Raxaul) considerably varied from party to party. The prevailing prices of petroleum fuels in 1991 is much higher than in 1989, particularly for fuels used in transportation. The major considerations involved in the pricing of petroleum products are:

a) The prices of petroleum products in Nepal had always been reflective of international prices. The pricing policies included cost recovery objectives and economic efficiency. Thus retail prices primarily reflected the border costs and government revenue requirements until 1989 (Table 5). But the trend is entirely different in 1992. All the major petroleum fuels except petrol have been subsidized by the Government since the Gulf War in 1990 and NOC is reportedly bearing a loss of about Rs.50 million per month. The change in pricing trend is apparent from the cost breakdown of selected petroleum fuels for 1991 where the retail prices of all major fuels except petrol are lower than the operating costs of NOC (Table 6).

b) The fixation of price levels for petroleum fuels also reflects a trade off between government revenue requirement and social considerations. (Motor spirit or petrol is considered as a luxury item and thus taxed heavily so that the major part of the total cost goes to the government treasury as taxes and duties. On the other hand, high speed diesel and kerosene have lower taxes due to social needs since higher taxes on diesel would increase the transportation cost of goods and services and thereby affect the common people in general. Similarly, high kerosene prices would adversely affect the low income households).

c) The CIF border prices of all petroleum products in Nepal are much higher than the international price in open market. (The CIF border prices of all petroleum products include not only freight and insurance from the international market to the Indian port but also handling charge by India and overland transportation through Indian territory up to the border point.)

d) Further the economic prices of petroleum fuels are higher than the CIF border prices since the internal transportation cost should be added to them.

e) The NOC overhead costs (establishment expenditures, interest, depreciation and miscellaneous expenses) are charged in such a way that they vary from fuel to fuel.

f) Pricing of petroleum products in Nepal is also directly affected by the Indian retail prices due to the open border. It is often necessary to fix the retail prices of petroleum fuels in Nepal in line with the Indian prices so that the products will not flow across the border one way or the another.

The economic costs of the selected oil products landed at Kathmandu Valley can be calculated from Table 5 and 6 by omitting custom duties and taxes. Based on these prices, the economic cost of energy by types of fuel is calculated both in terms of Rs/GJ and US$/GJ in Table 7 with the basis for estimation given in the foot-notes of the same table. It is apparent that the economic costs of all petroleum fuels have substantially changed before and after the trade and transit impasse between India and Nepal. The retail prices of petroleum fuels also reflect the similar trend except for diesel and kerosene which have recorded very little change in their energy costs during the period under consideration. LPG is an exception where the retail energy price in terms of US dollars has gone down due to the appreciable change in the exchange rate of US dollar between 1989 and 1991.

TABLE 5

Cost Break - Down of Petroleum Products (March, 1989)

Item	MS	HSD	SKO	LDO	ATF	FO	LPG
CIF Border Price (Inv. Price/Raxaul	3538.82 (27.4)	4016.04 (53.5)	3641.39 (63.3)	3820.94 (58.4)	3568.4 (61.5)	3066.85 (52.8)	7125.27 (62.1)
Custom Duty	5880.00 (45.6)	1635.00 (21.8)	300.00 (5.2)	240.08 (3.7)	880.00 (14.8)	160.00 (2.8)	
Sales Tax	941.88 (7.3)	282.55 (3.8)	- (0.0)	203.05 (3.1)	763.9 (13.2)	153.21 (2.6)	
Road/Bridge Tax	200.00 (1.6)	200.00 (2.7)	- (0.0)	- (0.0)	- (0.0)	- (0.0)	
Transport (RAXAUAL -KTM)	334.94 (2.6)	334.48 (4.5)	334.48 (5.8)	367.93 (5.6)	343.70 (5.9)	704.83 (12.1)	
Dealer's Commission	252.94 (2.0)	147.06 (2.0)	112.75 (2.0)	254.29 (3.9)	- (0.0)	- (0.0)	
Other Costs	1751.88 (13.6)	884.87 (11.8)	1361.38 (23.7)	1658.79 (25.3)	264.00 (4.6)	1723.28 (29.7)	
Retail Price	12900.00 (100.00)	7500.00 (100.00)	5750.00 (100.00)	6545.00 (100.00)	5800.00 (100.00)	5808.17 (100.00)	11478.81 (100.00)
Economic Price	3873.3	4350.52	3975.87	4188.87	3912.10	3771.68	
Inv.Price	21.81	24.75	22.44	23.55	21.99	18.90	

Note : Data within paranthesis are percentage

Source : Ministry of Supply quoted in "Background Paper for Energy Issue as options and Eighth Five Year Plan", WECS (18)

TABLE 6

Cost Break-Down of Petroleum Products (February - July, 1991)

(Unit : Rs/KL except LPG in Rs/MT)

Item	Petrol	Diesel	Kerosene	ATF	LPG
CIF Border Price` (Inv.Price/Raxaul)	7803.29 (41.77)	8863.14 (68.32)	8230.13 (78.07)	8935.04 (57.02)	12487.00 (61.84)
Custom Duty	5880.00 (31.48)	1155.00 (8.90)	300.00 (2.84)	955.00 (6.09)	500.00 (2.47)
Sales Tax	1407.35 (7.53)	523.07 (4.03)	-	1550.52 (9.90)	680.60 (3.37)
Road/Bridge Tax	200.00 (1.07)	200.00 (1.54)	-	-	-
Transport cost (Raxaul-Kathmandu)	597.62 (3.20)	597.62 (4.61)	597.62 (5.67)	597.62 (3.81)	2477.25 (12.27)
Dealers Commission	728.16 (3.90)	291.26 (2.25)	233.01 (2.21)	-	700.00 (3.47)
Other Costs	2063.11 (11.05)	1342.65 (10.35)	1181.56 (11.21)	3631.42 (23.80)	3347.80 (16.58)
Total Cost	18679.53 (100.00)	12972.74 (100.00)	10542.32 (100.00)	15669.60 (100.00)	20193.34 (100.00)
Retail Price	25000.00	10000.00	8000.00	15570.00	15140.00
Economic Price	8400.91 (44.97)	9460.76 (72.93)	8827.75 (83.74)	9532.66 (60.83)	14964.25 (74.11)
Invoice Price US $/Barrel Eq)	-	38.03	36.36	-	-

Source : Department of Mines & Geology, Petroleum Price Statistice.(6)

TABLE 7

Comparision of Economic Costs & Retail Prices 1989 & 1992

	ECONOMIC COST				RETAIL PRICE			
	1989		1991		1989		1991	
FUEL ITEM	(Rs/GJ)	($/GJ)	(Rs/GJ)	($/GJ)	(Rs/GJ)	($/GJ)	(Rs/GJ)	($/GJ)
1.Petrol	115.97	4.49	251.52	7.11	386.22	14.96	748.50	21.14
2.Diesel	115.09	4.46	250.26	6.75	198.40	7.69	264.55	7.14
3.Kerosene	109.53	4.25	243.19	6.76	158.40	6.14	220.38	6.12
4.ATF	107.77	4.18	262.61	7.42	159.78	6.19	428.93	12.12
5.LPG	173.00	6.71	304.17	8.59	233.31	9.04	307.72	8.69

Notes:

1. Energy content of different fuels are taken from WECS (5): Petrol 33.4 GJ/KL; Diesel 37.8 GJ/KL; Kerosene 36.3 GJ/KL; ATF 36.3 GJ/KL; and LPG 49.2 GJ/Mt.

2. Conversion rates: All procurements made in March, 1989 except LPG were at the exchange rate of 1 US$ = Rs. 25.80. LPG was exchanged with India so that the procurement or invoice price is not specified. The transport cost of LPG is estimated and the price is converted into U.S dollars at the then prevailing exchange rate.

Only two items, namely, diesel and kerosene were imported in 1991 from overseas and exchanged with India for other required items. Hence the invoice price of other items in U.S dollars per barrel are not given. Further, the 1991 procurements refer to the weighted average price for 6 months procurement (February-July, 1991). NOC could not make available the quantity and price of each import. The exchange rate of U.S dollar had fluctuated very widely between the period under consideration from 1 US$ = Rs 32.10 (selling rate to 1US$ Rs. 42.50. Hence the simple average of exchange rates for that period, which is 1 US$ = Rs 35.40, is considered for approximation of energy costs in terms of U.S. dollars for petrol, ATF and LPG. Diesel and Kerosene energy costs and calculated at actual invoice prices in U.S. dollars i.e. 1 US$ = Rs. 37.06 for diesel and 1 US$ = Rs. 35.99 for kerosene.

1.4 Price Elasticity of Petroleum Fuels in Transport Sector

The prices of petroleum fuels are increasing continuously over time. The retail prices of selected fuels in Kathmandu from 1973 to 1991/92 (Table 4) show that the prices of diesel and petrol have increased more than 5 times and 8 times respectively in 1991/92 form 1973 level. Despite the escalation in prices, the quantity of fuels consumed in Nepal have slowly but steadily increased (e.g., diesel consumption increased more than 4.7 times and petrol more than 2.3 times between 1974/75 and 1990/91 viz Table 3). This would mean that the demand for petroleum fuels in transportation is relatively inelastic even though the growth in consumption over time could be largely explained in terms of expansion of infrastructural facility as well as the increase in the number of vehicles plying in Nepalese roads.

Modern transport sector consumes only commercial fuels i.e., the energy consumption in this sector is fully monetized. As such, the demand for fuels is sensitive to price. But the willingness and ability of consumers to pay need to be distinguished between private vehicle owners and the general transportation service enterprises. Needless to say, the private vehicle owners, which represent about the majority of light vehicle registration in Nepal are expected to adjust their fuel consumption according to the market prices. On the other hand, the transportation service enterprises will bear the initial cost of fuels, but they will ultimately shift it to the consumers on the prices of goods and services. As the transportation of goods and services is essential in the economy and consumes the bulk of fuels in this sector, the demand for petroleum fuels is relatively inelastic in the latter case.

1.5 Comparative Cost Analysis of Hydrogen with Petrol and Diesel in Transport Sector

The competitiveness of hydrogen as a fuel with respect to petrol and diesel in Nepal will depend upon their relative economic costs. In addition, the use of fossil fuels entails environmental costs as against the clean, renewable hydrogen energy which must also be taken into consideration. Finally, the relative efficiencies of hydrogen with respect to petrol and diesel in the proposed transport end-uses must also be taken into account for the comparative cost analysis. Hence the conceptual framework developed by Dr. T.N. Veziroglu has been adopted here which defines a societal or effective cost to cover production cost, environmental cost and utilization efficiency, as follows (7):

$$S_s = [C_s + E_s (P^s / P_f)] n^f / n_s$$

where:

S_s	-	Societal cost of a synthetic fuel
C_s	-	Production cost of synthetic fuel
E_s	-	Environmental cost of synthetic fuel
P_f	-	Pollution factor of synthetic fuel
P_s	-	Pollution factor of fossil fuel
n_f	-	Utilization efficiency of fossil fuel
n_s	-	Utilization efficiency of synthetic fuel

The societal or effective cost is the total cost that the society has to pay for use of a particular fuel and it will be used for the comparative cost analysis of hydrogen with petrol and diesel in transport sector. For this purpose, the production/economic costs, environmental costs and relative efficiencies of utilization of different fuels will be analyzed separately in three parts and then an attempt will be made to estimate their societal costs.

1.5.1 Production/Economic Costs

The cost structures of imported petrol and diesel in 1991 were presented in Table 6 earlier together with the economic as well as retail prices of these products in Kathmandu Valley. Based on these information, the economic and retail prices of both petrol and diesel were calculated in Table 7 in terms of Rs/GJ and U.S. /GJ. The analysis of production cost of electrolytic hydrogen in Nepal does not fall within the scope of this study. But the production costs of electrolytic hydrogen based on hydro power are available in various literatures which based on hydro power are available in various literatures which differ in a rather wide range depending upon many factors: a) the scale of operation (large-scale/medium-scale/small-scale); b) the nature of operation (continuous/off-peak); c) type of electrolysers used (conventional/advanced alkaline/solid polymer/high temperature); d) cost of electricity for hydrogen production (industrial tariff/off-peak); e) type of hydro plant (old/new), etc. The basis for the cost estimates, however, are not always clearly specified in the literatures. Despite the relatively wide variations in current estimates of hydrogen production costs, it is generally accepted that these costs will be reduced by the turn of this century as the new electrolysis technologies will advance and the unit size of equipment will increase (7,8,9).

A recent estimate of the production costs of hydrogen b) scale and nature of operations are presented by O. Bugge (10) which is based on the results emanating from the Commission of the European Communities research programme (11). The hydrogen production costs for 1990 is estimated to range from US$ 9.42 to 23.24/GJ (Table 8). While the electricity cost appears to dominate the production cost in large plants, the capital cost is the main cost component in case of very small plants. The estimated hydrogen production cost in case of surplus electricity (i.e, without electricity cost) is only U.S$ 7.23/GJ including storage cost which amounts to U.S$2.24/GJ. In fact, the hydrogen production cost based on surplus hydroelectric is estimated in other study as low as US$4-7/GJ (9).

The above estimates refer to the production cost of gaseous hydrogen. But hydrogen finds application in gaseous (GH_2), liquid (LH_2) and hydride (MH_2) forms. Further, the costs of LH_2 and MH_2 are higher than GH_2 due to additional costs involved in liquefaction and hydration. Even if the use of MH_2 will be excluded due to its relatively high cost at this stage, it is necessary to consider hydrogen application in GH_2 and LH_2 forms, particularly for automotive use. These cost estimates are provided in another recent paper by T.N. Veziroglu (7) which estimates the large-scale production cost of hydrogen from hydroelectricity for 1990 at US$ 11.51/GJ for GH_2 and US$ 14.39/GJ for LH_2. The production cost of GH_2 here is in the same range as in earlier study (10). Hence the latter production costs of GH_2 and LH_2 will be used in the analysis.

TABLE 8

Estimated Production Costs for Hydrogen

	Scale of Operation			
	Large Plant		Small Plant	Very Small Plant
Nature of Operation/Cost	Cont.[1]	Off-peka[2]	Cont.[3]	Cont[4]
Production Cost	14.2	9.42	15.73	23.34
Storage Cost	-	2.24	-	-
Gross Production C	14.2	11.66	15.73	23.34
Gross Production C for Surplus electricity no cost	4.77 (Incl.Storage)	7.23	5.34	11.14

Source : Bugge O; "Benefits of Hydrogen Energy systems to the Developing Countries " (10) Abridged

Basis for Cost Estimation:

1. Hydrogen production of electrolysis. Economic evaluation for a large plant in France for year 1990.

   Annual hydrogen demand 845,000,000 Nm^3 (equivalent 200,000 tonnes gasoline); Plant output 1,66,692 Nm^3 continuous operation. Price for electric power 0.US$/Kwh (including the price for industrial and off peak power).

2. Hydrogen production by electrolysis. Economic evaluation for a large plant in France for year 1990.

   Annual hydrogen demand 845,000,000 Nm^3 (equivalent, 200,000 tonnes gasoline); Plant output 165,362 Nm^3 offpeak operation connected to underground storage. Price for electric power 0.023 US$/Kwh (including the price industrial and offpeak power).

3. Hydrogen production by electrolysis. Economic evaluation for a medium size plant in France for year 1990.

   Annual hydrogen demand 20,000,000 Nm^3 (equivalent to 5 tonnes gasoline). Plant output 2,525 Nm^3/h. Continuous operation when the oxygen byproduct is saleable. Price electric power 0.025 US$/kwh (including the price industrial and offpeak power).

4. Hydrogen production by electrolysis. Economic evaluation for a small plant in France for year 1990.

   Annual hydrogen demand 119,000 Nm3 (equivalent to 30 tonnes gasoline); Plant output 15 Nm^3/h, continuous operation. Price for electric power 0.031 US$/kwh (including the price for industrial and offpeak power).

Calculations based on Glyun P, Prospects for Hydrogen from Advanced Water Electrolysis (11).

The comparative economic/production costs of petrol, diesel GH_2 and LH_2 are assessed. At first glance, both GH_2 and LH_2 options do not appear competitive with conventional petrol and diesel alternatives so that they can hardly substitute fossil fuels in transport sector of Nepal. But the consideration of surplus hydroelectricity tilts the balance on favour of hydrogen. As the economic cost of surplus hydroelectricity is zero, it can be deducted from the estimated production costs of hydrogen for economic analysis. Thus the economic cost of GH_2 based on surplus hydroelectricity is in competitive range with the economic cost of imported petrol and diesel in Nepal. The economic cost of LH_2 is slightly higher (about 25 percent) than the economic cost of GH_2 owing to the additional cost of liquefaction.

The production cost of hydrogen from off-peak or seasonal surplus hydroenergy needs further elaboration here. In this case, both the capacity factor and cost of electricity are correlated. As the electrolysis plant has to operate only at off-peak hours, the commercial price of electricity for this purpose will have to be considerably lower than the prevailing industrial tariff paid by other industries. Hence the price of surplus electricity for hydrogen production is likely to be a function of annual time the power will be provided for the operation of electrolysis plant: the longer the guaranteed availability of power, the higher is likely to be the price and vice versa. This would then imply that for electrolysis plant operation on the basis of surplus electricity, the reduction in specific energy cost for hydrogen production would increase the specific capital costs. But both the energy and capital costs of electrolytic hydrogen depends upon the power density of electrolyzers which is again proportional to current density.

The cost of electrolytic hydrogen from off-peak power was investigated by S. Stucki (12) using a simple model for optimization where the current density at which the electrolysis plant would be run and the annual time of availability of electric power are considered as the variable factors for the study. The conclusion of this study shows that an optimum can be found with respect to time of operation or electricity price, but it is little sensitive on the performance and the specific costs of the electrolysis equipment used. On the other hand, the resulting cost of hydrogen depends upon the electrolysis technology employed. Thus the medium efficiency, low cost electrolyzers (e.g., those specifically designed for off-peak power application in France) seems to be best suited for hydrogen production from surplus or off-peak energy. The highly efficient and expensive advanced

designs of electrolyzers are more suitable for continuous operation using more expensive electricity, but they are just about competitive in off-peak application provided that they can be run technically at the postulated very high current densities (12). The finding of this study has important implications for a country like Nepal since it indicates that the cost of hydroelectric hydrogen from surplus or off-peak electricity can be brought down by the selection of appropriate (medium efficiency, low cost) electrolyzer technology for operation in local condition.

At this juncture, it is pertinent to stress here that the capital costs of electrolysis plant, which is the second highest cost component after electricity, can be further reduced by adapting appropriate depreciation policy. The useful life of conventional electrolyzers is 20 to 25 years in practice even though the commercial practice is to depreciate them at a much faster rate of 10 to 12 percent per annum so as to recover the investment capital as quickly as possible. A modified depreciation policy is anyway essential for operation of electrolysis plant based on available surplus energy since it will have much longer useful life than the conventional plant by the virtue of being only a fraction of time in operation than in the latter case (330 days or 7920 hours per annum). Only the physical obsolescence (but not the technical obsolescence) is to be considered here since the medium efficiency technology appears to be preferable for operation of electrolyzers in the case. Thus there is ample scope for reducing the production cost of surplus electricity based hydrogen so as to make it competitive with the economic costs of imported petrol and diesel in Nepal.

1.5.2 Environmental Costs

The major environmental problems directly associated with the consumption of fossil fuels are air pollution, acid rains and greenhouse gas effects such as the climatic changes and the consequent rise in the sea level. These adverse impacts of fossil fuel consumption were known for a long time, but attempts have been made to evaluate these costs only in recent years with the growing environmental concern throughout the world. The detailed estimates of the damage caused by fossil fuels on various elements of biosphere are available today and a summary of these costs is presented in Table 9.

The estimated total cost of environmental damage due to fossil fuels is US$ 10.62/GJ which is more than the economic cost of imported petrol ($7.11/GJ) and diesel ($6.75/GJ) in Nepal in 1991. It is quite significant in terms of retail prices of petrol ($21.14/GJ) and diesel ($7.14/GJ) in Kathmandu as well. This is the price our society pays in addition to the economic cost for fossil fuel use. Thus the environmental damage cost is indeed large, but it does not include the costs of human discomfort and any induced climatic changes so that the actual environmental cost of fossil fuel will be still higher (7).

TABLE 9

Summary of the Estimates of the Fossil Fuel Damage

Type of Damage	Damage per Unit of Fossil Fuel Energy (1980 $/GJ)
Effects on Humans	376
Effects on Fresh Water Sources & Resources	0.59
Effects on Farm Produce Plants & Forest	1.25
Effects on Animals	0.4
Effects on Buildings	0.73
Effects on Coasts & Beaches	0.17
Effects of Rising Oceans	0.37
Effects of Strip Mining	0.15
Effects of Rising Temperatures	3.2
Total	$ 10.62/GJ

Source : Veziroglu T.N. (7)

The environmental damage cost given above refers to the use of 1 GJ of coal or oil. But when a synthetic fuel is produced from fossil fuel, more than 1 GJ of fossil fuel is consumed. Hence the environmental cost is greater than the specified U.S.$10.62/GJ value so that:

$$E_s = E_f (P_s / P_f)$$

where:

E_s - Environmental damage cost of synthetic fuel
E_f - Environmental damage cost of fossil fuel
P_s - Pollution factor of synthetic fuel
P_f - Pollution factor of fossil fuel

The pollution factors has been represented by the emission of CO_2 due to the lack of data which are given in Table 10.

TABLE 10

Pollution Factor

Fuel		Pollution Factor CO2 Emission (Kg/GJ)
1.	Coal GH2	116.3
2.	Hydro GH2	-
3.	Solar GH2	-
4.	SNG	116.3
5	Coal LH2	145.4
6	Hydro LH2	-
7	Solar LH2	-
8	Syn-Gas	131.6
9	Syn-Jet	131.6
10	Coal	85.5
11	Petrol	76.5
12	Natural Gas	48.4
	Mean Fossil (Coal + Petrol)	81

Source : Veziroglu T.N (7)

The pollution caused by motor vehicle exhaust emissions have also been studied in many countries. In this respect, the studies undertaken by the Swedish Communication Department in cooperation with the University of Gothernburg in 1983 and 1987 can be cited here (Table 11). These studies analyzed the cost per litre of petrol consumption in city traffic in terms of vegetation damage, corrosion, general pollution, annoyance and health costs. The pollution bill to the society, according to these studies, were US$ 0.36 per litre petrol ($10.78/GJ) in city drive and U.S$ 0.12 per litre petrol ($3.59/GJ) in country drive. Moreover, the society bill had increased 16 percent per annum between 1983 and 1987 period (13). The findings of Swedish studies, however, cannot be directly extended to Nepal even though they provide an insight into the magnitude of costs involved.

The available evidences suggest that Kathmandu Valley is subject to increasing air pollution. The suspended particulates and sulphur dioxide levels have increased with the growth of industrial activities as well as the number of motor vehicles in the city. While the brick kilns and the cement plant located in the periphery of Kathmandu Valley are the major sources of air pollution in industrial sector, the motor vehicle traffic has also assumed an important role in recent years, particularly due to the old vehicles which are characterized not only by high fuel consumption but also by excessive emission of harmful gases such as carbon dioxide, carbon monoxide, nitrogen oxides, etc.

The observed value of particulate loading for Kathmandu ranged 1,500 - 3,000 micrograms per cubic metre in 1987 (as against the WHO guideline of 60 to 90 mg/m^3) which was probably due to absence of any regulation on vehicle exhaust (14). The use of leaded petrol is another source of air pollution in Kathmandu Valley. Close correlation was observed between lead content and vehicle movement in Kathmandu (15). As yet air pollution is not systematically monitored in Nepal so that there is paucity of data in this respect. Nevertheless, the increasing air pollution in the urban centres has severe health implications such as the rise in respiratory diseases, emphysema and chronic bronchitis. The adverse impacts of air pollution on historical buildings and monuments, the roots of our cultural heritage and civilization, have yet to be evaluated.

This state of affairs could be attributed to the lack of any effective legislations for air pollution control. The setting of standards for control of emissions alone will not, however, solve the problem since we can hardly discard all the old vehicles plying in our roads in view of the capital shortage for their replacement. Under these circumstances, a switch to hydrogen as an automotive fuel will considerably mitigate the pollution problem.

It is pertinent to note here that HMG/N has imposed heavy taxes on the use of imported petroleum products in Nepal even though this step was basically taken due to the need to increase government revenue rather than due to purely environmental concern. This fact is evident from the retail prices of petrol and diesel which are much higher than their economic costs. Although the economic costs of imported petrol and diesel are low and almost equal to each other, the present HMG/N policy of treating petrol as a luxury item with heavy taxes and diesel as an essential commodity with low taxes has artificially created a situation where the retail price of petrol is several times higher than that of diesel. The present discriminatory practice of taxing petrol and diesel at different rates, however, is not compatible from the environmental viewpoint, even though the social considerations may dictate otherwise. In fact, diesel has much higher pollution cost than petrol (Table 12). The taxes imposed at present by HMG/N on petrol and diesel, which are approximated by the differences between their retail and economic prices, are given in Table - 12. While diesel is subject to a low tax of U.S$ 0.39/GJ, petrol has a penalty of U.S $14.03/GJ. Thus at the existing tax structure, petrol is subjected to higher taxation than justified by environmental damage of its use whereas diesel remain very much undertaxed.

TABLE 11

Societal Costs for Exhaust from Vehicles

Prices in City Traffic 1988 (U.S. Cents/Litre)

Vehicle Type/Fuel	Vegetatio Damage	Corrosion	General Pollution	Annoys	Health Costs	Total
Person Wagon (Petrol)	6	-	4	7	19	36
Truck (Petrol)	6	-	3	6	19	34
Person Wagon (Diesel)	4	10	17	6	15	52
Truck (Diesel)	8	14	11	7	35	75
Bus (Diesel)	9	13	9	6	36	73

Note : Prices above do not include CO_2 damage value.
Source : Hydrogen Organization (13)

TABLE 12

Taxes Imposed by HMG/N on Petrol and Diesel

	Retail Prices		Economic Prices		Tax Imposed	
Item	(Rs/GJ)	($/GJ)	(Rs/GJ)	($/GJ)	(Rs/GJ)	($/GJ)
Petrol	748.50	21.14	251.52	7.11	496.98	14.03
Diesel	264.55	7.14	250.26	6.75	14.29	0.39

1.5.3 Relative Efficiencies of Utilization

The relative end-use efficiencies of conventional I.C engines using petrol, diesel and hydrogen fuels should be taken into consideration for the comparative cost analysis. In this respect, the performance of experimental hydrogen vehicle engines have demonstrated much higher efficiency in comparison to petrol engine (Table 13). As a matter of fact, the performance of hydrogen vehicles shows marked variations from experiment to experiment with efficiencies ranging from +5 to +6 percent relative to petrol. On the average, a value of 22 percent better overall efficiency has been suggested (16).

TABLE 13

Performance of Hydrogen Vehicles and Engines)
(Changes are relative to Petrol by using 100 percent H_2)

The Vehicle	Fuel Storage	Efficiency (% Relative to Petrol)	Power (% Relative to Petrol)
LAUL/DEVLR Buick	LH_2	+22%	Accceleration times 2% longer
Masashi-4,3-Cyl	LH_2	+30%	+25% max. power
Masashi-5,3-Cyl C1	LH_2	--	upto 25% more power
Masashi-7, C1 truck	LH_2	+18%	+11% max. power
MIni-bus	GH_2 (Cylinder)	+15%	Reached speed limit on hills, fully loaded
CYI, Toyota Lab Engine	GH_2	+5 to +13%	upto 13% more power
310 Vans	586 Kg TiVMn hydride	upto + 15%	Top speed 130 Km/h
Cyl, lab engine	GH_2	+45%	--
Cyl, Car	70 Kg TiFeMn hydride	+63%	23% less power
Cyl, BMW 520	LH_2 external mixing	--	11% less max. power
Cyl, BMW 7451	LH_2 Direct injection	--	6 % less max. power
Cyl, Lab engine	GH_2	+16% to +45%	--

Source : Deluchi M.A. (17) abridged.

The end-use efficiency of hydrogen in road transportation however, differ according to its form (i.e., gas or liquid) as well as nature of application (i.e., I.C. engines or fuel cells). For this purpose, the end-use efficiencies of hydrogen adopted for the present analysis are given in Table 14.

TABLE 14

End-Use Efficiencies of Hydrogen and Petrol

Application	Fuel	Efficiency (%)
A. I.C. Engines	Petrol	25
	GH_2	30
	LH_2	33
B. Fuel Cells	GH_2	70

Source : Veziroglu T.N. (7)

1.5.4 Societal Costs of Petrol, Diesel and Hydrogen for Transportation in Nepal

An attempt has been made in this section to estimate societal costs of petrol, diesel and hydrogen for transportation by summarizing the earlier discussions. As the actual production cost of hydrogen based on surplus hydroelectricity in Nepal is not available at this stage, production cost of hydrogen in large-scale plant earlier has been taken as a proxy in this study. The earlier discussion indicate that the production cost of hydrogen on the basic surplus hydroelectricity is likely to be in the range of proxy production cost assumed here so that this comparative analysis is likely to be realistic by all means. In context, it should be stressed here that this is the first exercise of its kind in Nepal and hence the societal costs also be interpreted with utmost caution. The calculated social costs are presented in Table 15.

TABLE 15

Societal Costs of Petrol Diesel and Hydrogen

		Costs U.S. $/GJ		Utilization		Societal Present
Application	Fuel	Economic	Environmental	Efficiency (%)	Cost (US $/GJ)	Retail Cost (US $/GJ)
I.C. Engine	Petrol[1]	7.11	10.62	25	17.14	21.14
	Diesel[1]	6.75	10.62	25	16.78	7.14
	GH_2	11.51 (Max)	-	30	9.59	-
	LH_2	14.39 (Max)	-	33	10.90	-
Fuel Cell	GH_2	11.51 (Max)	-	70	4.11	-

Note : [1] The pollution factors will be considered in case of fossil fuels from Table 10.

For application in I.C engine, GH_2 has the lowest social or effective cost followed by LH_2. Both petrol and diesel have a much higher societal costs for use in I.C engine than GH_2. The least societal cost among all alternatives is in case of application with fuel cells.

The present HMG/N petroleum pricing policy has significant implications for the substitution of petrol and diesel hydrogen in Nepal. As the retail price of petrol is artificially boosted with government taxes, hydrogen is fully competitive with petrol in Kathmandu Valley. Hydrogen production can, therefore generate substantial revenue to electricity authority even surplus energy for petroleum substitution in Nepal. On the other hand, the substitution of diesel with hydrogen, which is a preferred alternative for mass transportation, is only possible with I.C engine if the surplus electricity will be available much below the existing electricity tariff. The simultaneous substitution of both diesel and petrol with hydrogen appears to offer some scope to cross subsidize diesel with petrol. But in view of the six times larger quantity of diesel consumption than petrol in Nepal in 1990/91, this measure has only a limited validity. Hence a revision on government policy on diesel appears to be essential for its substitution with hydrogen in Nepal. Diesel substitution with hydrogen, however, will be possible even under the existing retail price structure if hydrogen application with fuel cell will be feasible.

1.6 Projected Demand for Hydrogen in Automotive Use

The demand projection for conventional petrol and diesel fuels are undertaken by trend-method up to 2000/2001 period on the basis of available time-series data (Table 3). Both linear and non-linear projections have been carried out, but the non-linear projections are selected here which gave better fit than the linear projections. The projected demand for petrol and diesel are calculated both in metric tonnes as well as GJ (Table 16).

The derived demand for hydrogen in road transport is then presented in Table 17. The derived demand for hydrogen differs considerably according to the application of hydrogen; the lowest demand is for GH_2 with fuel cells followed by LH_2 and GH_2 in I.C. engines. It is apparent that considerable energy saving can be achieved by the substitution of petrol and diesel with hydrogen due to the higher end-use efficiencies of hydrogen in all forms than conventional fossil fuels.

TABLE 16

Projected Demand for Petrol and Diesel

Petrol........ $Y_p = 14.0 + 0.7\,x + 0.1\,x2$

Diesel........ $Y_D = 63.1 + 4.3\,x + 0.4\,x2$

	Projected Demand for Petrol		Projected Demand for Diesel	
Year	'000MT	10^3 GJ	'000MT	10^3 GJ
1991/92	21.80	1028.96	103.30	4751.80
1992/93	23.80	1123.36	112.80	5188.80
1993/94	26.00	1227.20	123.10	5662.60
1994/95	28.40	1340.48	134.20	6173.20
1995/96	31.00	1463.20	146.10	6720.60
1996/97	33.80	1595.36	158.80	7304.80
1997/98	36.80	1736.96	172.30	7925.80
1998/99	40.00	1888.00	186.60	8583.60
1999/2000	43.40	2048.48	201.70	9278.20
2000/2000	47.00	2218.40	217.60	10009.60

Note : Energy content of petrol 1 MT = 47.2 GJ and diesel 1 MT = 46 GJ

TABLE 17

Derived Demand for Hydrogen in Road Transport

Year	Total Projected Demand for Petrol and Diesel (10^3 GJ)	Derived Demand for Hydrogen (10^3 GJ) GH$_2$-I.C Engine Efficiency 30 %	LH$_2$-I.C Engine Efficiency 33 %	GH$_2$ - Fuel Cells Efficiency 70 %
1991/92	5780.76	4817.30	4379.36	2064.56
1992/93	6312.16	5260.13	4781.94	2254.34
1993/94	6889.80	5741.50	5219.55	2460.64
1994/95	7513.68	6261.40	5692.18	2683.46
1995/96	8183.80	6819.83	6199.85	2922.79
1996/97	8900.16	7416.80	6742.55	3178.63
1997/98	9662.76	8052.30	7320.27	3450.99
1998/99	10471.60	8726.33	7933.03	3739.86
1999/2001	11326.68	9438.90	8580.82	4045.24
2000/2001	12228.00	10190.00	9263.64	4367.14

2. Hydrogen Demand in Domestic Use

2.1 Domestic Sector

The per capita energy consumption in Nepal is only about 14 GJ (or 326 Kg oil equivalent) which is among the lowest in the world. The domestic sector has a disproportionately large share of 93.48 percent in the overall energy consumption which means that, for all practical purpose, the national energy consumption can be identified with domestic energy consumption. Nevertheless, practically all the household activities such as agro-processing, collection of firewood, water fetching from nearby source, etc are carried out by human labour at this stage of economic development in Nepal and fuel energy is exclusively used for cooking, heating and lighting operations only.

The present level of domestic energy consumption in Nepal is basically a function of 3 factors: climate, availability of fuels and income level of households. The climatic conditions of Nepal necessitate space heating in the northern Himalayan region during the winter and air cooling in the Southern Terai belt during the summer period. Hence the domestic energy consumption, as a rule, decreases from north to south. But space conditioning is not widely practised unless essential simply because the majority of population cannot afford it. Under these circumstances, space heating is generally practised only in Himalayan region for about 5 months and in urban hill areas for about 2 months. On the other hand, air cooling is practised in areas where electricity is available, particularly in urban Terai region.

While the heating of residential building shares a major portion of the total energy consumed in the Himalayan region, it is very much restricted in the midhills due to milder climatic conditions and general scarcity of fuels (firewood) for this purpose. Space heating, however, is often practised as a multi-purpose operation in Himalayan region i.e., a central stove with several potholes simultaneously serves for cooking, water heating, space heating and sometimes even for household lighting purpose. It is, therefore, very difficult to distinguish the different end-uses of energy in domestic sector in this region. Further, the mountainous region has only about 10 percent of the total population in Nepal so that the energy consumption in space heating (for which a separate estimate is not available) is a small fraction of the total energy consumption in domestic sector of Nepal.

Cooking is the most important operation in the domestic sector. In fact, it is estimated that more than 75 percent of domestic energy is used for cooking purpose in Nepal (18). Some of the cooking energy is, however, used for agro-processing in cottage industry, which is again a combined operation at the village level.

The fuels at present consumed in the domestic sector can be classified into two categories, namely, commercial and non-commercial fuels. While the commercial fuels such as kerosene, LPG and electricity involve monetary cost, the non-commercial fuels such as firewood, agricultural wastes and animal dung are gathered by the household members, including women and children, from nearby fields and forests so that they have no direct cost. Thus the commercial or processed fuels, which have higher energy density, are mainly consumed in urban sector whereas the non-commercial or raw fuels are mostly used in rural sector. As a matter of fact, all the fuels consumed in urban sector are commercial fuels (even firewood is a commercial item in this case) except a small quantity of agro-wastes and cow dung consumed by agricultural community at the urban fringe areas. On the other hand, all the rural households basically consume non-commercial fuels except kerosene used for lighting purpose which is a commercial fuel also in the rural context.

2.2 Energy Consumption Patterns in Domestic Sector

The basic parameters of domestic energy consumption in cooking, heating and lighting operations depend upon a host of factors. First of all, the climatic and cultural difference across geophysical regions considerably affect the pattern of domestic energy consumption in the specified activities. Hence the domestic energy consumption pattern differ between mountain hill and Terai strata in Nepal even though cooking is the basic energy consuming domestic operation in all cases. Secondly, the rural and urban energy consumption patterns exhibit significant variations due to the difference in household income, availability of fuels, demonstration effect, etc. Once again cooking is the predominant end-use of domestic energy consumption also in urban households even though energy finds much more diversified applications here than in rural sector. In reality the cooking fuel consumption patterns are rather very complicated which also differ

kind of appliances employed in cooking, etc. Similarly, the household lighting energy consumption is a function of the type of fuels used, efficiencies of lighting appliances, duration of lighting required, etc.

The overwhelming reliance on traditional fuels is perhaps nowhere so apparent in Nepal as in case of domestic sector where they command together a share of as much as 98.4 percent of the energy consumption (Table-18). All these traditional fuels used for heat supply i.e. cooking as well as water and space heating purposes. The remaining 1.6 percent contribution is by petroleum products (in form of kerosene and LPG) electricity. Domestic sector consumes the bulk of imported kerosene (about 80.2 percent) for rural lighting, urban cooking space heating. Remaining 18.2 percent is used in commercial sector and 1 percent in industrial sector (2). Similarly, about 65 percent of the LPG is consumed in domestic sector for cooking. Remaining 35 percent is used in commercial sector (2). Electricity is used for light, heat (cooking, water and space heating) and work in domestic sector.

TABLE 18

Economic Costs of Cooking Fuels

		Energy Content		Economic Cost	
Fuels	Unit	(MJ/Unit)1/	Cost	(Rs/GJ)	(US $/GJ)
1. Firewood	(Kg)	16.7	3.20 2/	191.62	4.48
2. Electricity	(Kwh)	3.6	2.55 3/	708.34	16.55
3. Kerosene				243.19	6.76
4. LPG				304.17	8.59
5. Hydrogen	(GH_2)				11.51

Notes :

1_/ Energy content of fuels are taken from WECS report (2)

2_/ Kathmandu open market price is Rs. 120/md (37.5Kg) i.e., Rs. 3.2/Kg. The open market price reportedly goes up to Rs. 150/md depending upon the supply situation. Timber Corporation of Nepal (TCN) has a lower rate (Rs. 95/quintal), but the supply is neither adequate nor regular.

3_/ The minimum charge and rebate, which comprise only a small fraction of total cost is omitted and cost is calculated only on the basis of energy cost.

The analysis of domestic energy consumption by various end-uses in urban and rural sectors is not available at this stage. Nevertheless, an inference can be made on the basis of existing knowledge to reveal the general trend. This is possible because most of the domestic fuels can be directly associated with either urban and rural sector which is not evident from the aggregated data of consumption. On this basis, the use pattern of various fuels in urban and rural sectors in heating and lighting applications are inferred. It is apparent that certain forms of energy are exclusively used for heating in urban or rural sector whereas others find use in both sectors. Thus kerosene, LPG and electricity are typical urban heating fuels whereas agricultural residue and animal dung are exclusively used in rural sector. But firewood finds use for heating in both sectors even though demand in urban areas appears to be gradually declining due to its rising price as well as competition from commercial fuels. On the other hand, the household lighting fuels also reveal exclusive use pattern even though the choice is governed in this case by the supply factor. Electricity is the most preferred form of energy for lighting purpose and used wherever it is available. Kerosene is used as an alternative in unelectrified areas. As most of the urban areas are electrified (except some households in the fringe areas), electricity is the main source of urban household lighting. Similarly, kerosene serves as the major fuel for rural household lighting except in some electrified rural areas.

The distribution of domestic energy by end-uses was estimated which is based on the energy use pattern derived earlier. Although this analysis is the first approximation of its kind undertaken in Nepal, it reveals that about 98.5 percent of total domestic energy is used for heating alone (cooking, space heating, water heating, etc) whereas the remaining 1.5 percent is consumed in combined light, heat and work operations. The preponderance of heating energy is thus evident in Nepalese domestic scene.

The heating energy in domestic sector is supplied mainly in form of traditional fuels which have very low energy density. In addition, the efficiencies of these biofuels utilization in domestic stoves are also extremely low. For example, the average efficiency of firewood utilization is estimated at 10 percent whereas it is estimated at only 5 percent for agricultural wastes and animal dung (2). Hence the total bulk of domestic energy consumed in Nepal is excessively high in comparison to the actual effective heat utilization in that sector.

Given this situation, attempts have been made to conserve as well as substitute traditional biofuels in domestic sector. In this context, the technologies based on new and renewable energy sources (NRSE) intend, on the one hand, to conserve or increase the supply of traditional biofuels (e.g., through improved cooking stoves, agro-forestry, etc) and, on the other hand, to substitute them (biogas, solar cookers, storage cookers, etc). Hydrogen as an energy alternative is another option for this purpose.

2.3 Preconditions for Domestic Energy Substitution with Hydrogen in Nepal

Hydrogen as an energy alternative can theoretically substitute different kinds of domestic fuels used currently in heating applications, but several techno-economic as well as socio-cultural problems should be overcome for its practical application. The problems related to the substitution of commercial and non-commercial fuels in Nepal are very much different so that they will be dealt separately below.

Needless to say, the basic condition for substitution of commercial fuels is the techno-economic viability of hydrogen as an energy alternative with respect for these fuels (LPG, kerosene and electricity). In other words the substitution of commercial fuels with hydrogen will be possible only when appropriate hydrogen based technologies are available for specified end-uses and they are also cost competitive with other conventional, commercial fuels.

Further, hydrogen must also fulfil its socio-cultural acceptance as a domestic fuel. In this respect, hydrogen is like any other conventional gaseous fuels, but it is more hazardous in nature than the rest. Therefore the safety in storage and handling of hydrogen is of vital importance for its social acceptance. Hence the following conditions must be fulfilled for the substitution of commercial fuels with hydrogen in Nepal:

a) Favourable generation cost and competitive sales price of hydrogen in comparison with other commercial fuels;

b) Availability of appropriate hydrogen based technologies for domestic end-uses (particularly cooking) and their relative cost and useful life in comparison to other commercial energy based appliances (e.g. gas stoves, kerosene stoves, etc);

c) Fuel consumption efficiency of new technology vis a vis similar efficiencies of conventional technologies using commercial fuels;

d) Ease of operation and maintenance of hydrogen based appliances as compared to conventional appliances using commercial fuels; and

e) Safety of hydrogen in storage and handling operations in comparison with commercial fuels based in Nepal (LPG kerosene and electricity).

Since these information are not available at this stage, the techno-economic feasibility as well as social acceptance of hydrogen as a fuel to substitute commercial fuels in domestic uses have yet to be established in Nepal.

The substitution of non-commercial fuels with hydrogen in domestic sector involves more serious problems than in the former case. All the conditions mentioned above for commercial fuels substitutions with hydrogen are also applicable here. In addition, the issues related to ability and willingness of rural households to switch to hydrogen fuel need to be considered in this case.

The rural households have very low income at this stage which is barely sufficient for their survival Moreover, the income is generated mostly in kind in rural economy. The introduction of hydrogen as a household fuel involves monetary cost to purchase it. Further, the cooking operation represents the bulk of domestic energy consumption (unlike kerosene in lighting operation) so that a change from non-commercial to hydrogen energy will impose a heavy financial burden on the rural household which will compel them to spend a major chunk of their total cash income for the purchase of this fuel. Hence the increase in rural household income is another precondition for the substitution of non-commercial fuels with hydrogen. Alteratively, some appropriate institutional and organizational frameworks should be devised for the promotion of hydrogen as a domestic fuel in which the rural households can obtain hydrogen fuel free of cost for some specified works such as afforestation. But admittedly, this approach would require political commitment as well as people's participation to succeed in mass-scale.

The next issue pertains to the willingness of rural households to use commercial fuels. In this respect, the willingness of rural households to switch to hydrogen (for that matter, to any other commercial fuels) is questionable even if their income level will permit to do so. This is because the firewood collected from the nearby fields and forests by the family members is perceived as costless by individual households, though it has very high cost to the society: On the hand, hydrogen energy (or any other new and renewable form of energy) is cheap to the society but not to the households. Hence the rural households may resist the shift to hydrogen until the "free" availability of traditional fuels.

Given these constraints, priority must be assigned to the substitution of commercial fuels in urban sector with hydrogen. Selective application of hydrogen, however, will be possible in some rural areas where the household income is relatively high due to the growth of trekking tourism. Above all, hydrogen application as a fuel need to be linked with trekking tourism in remote Himalayan regions; it could cater the cooking and lighting energy needs of the tourists and at the same time protect the fragile environment.

2.4. Comparative Cost Analysis of Hydrogen with Domestic Cooking Fuels

The comparative cost analysis of domestic cooking fuels with hydrogen will be undertaken here by the same methodology which was adapted in case of transport sector earlier. The societal or effective costs of different fuels consumed in cooking operation will be again discussed under three separate headings i.e., efficiencies of utilization. But since the same fuel is used for cooking in different types of appliances having different end-use efficiencies, it is difficult to compare societal or effective cost of these fuels directly in this case. Hence the effective cost per GJ for each cooking fuel will be calculated taking into consideration the end-use efficiencies of all types of appliance in use for that particular fuel.

2.4.1 Production/Economic Costs

The main cooking fuels at present in use in Nepal are firewood, kerosene, LPG and electricity. Some of these fuels are import articles (kerosene and LPG) and the rest are supplied from indigenous sources. The economic costs of these fuels are very much different and some of them cannot be expressed in monetary terms.

First of all, it is a known fact that firewood has very high economic cost at this stage in Nepal which may be several times higher than its prevailing market prices in urban areas. But the rural sector consumes the bulk of this fuel without paying any monetary cost. In fact, the rural households perceive no "real" cost in firewood collection due to the lack of opportunity cost. The existence of disguised unemployment in agriculture has mainly contributed to this end. Despite this situation, firewood has an economic cost also in rural sector. Since the economic cost of firewood (which may vary from area to area depending upon a host of local factors) has not yet been calculated in Nepal, we shall assume its prevailing open market price in Kathmandu Valley as a proxy for its actual cost. Needless to say, it is a very conservative estimate.

The electricity tariff for domestic sector has been specified in terms of minimum charge and energy charge. The minimum charge is determined by meter capacity (ampere) which has some rebate units. The energy charge progressively increases with the level of consumption. It has been generally observed that the urban households which practice electric cooking have at least the meter capacity in 6 to 30 ampere range (the minimum charge for meter in this range is Rs 60 with 40 rebate units) and consume not less than 250 Kwh per month (electricity slab for 76-250 units is Rs 2.55 per unit). Electricity is, however,

consumed in such households for various purposes including refrigeration, water pumping, cloth washing, T.V, etc. Since cooking is the main load in these households, it is reasonable to describe highest energy charge within the specified 250 Kwh range for this purpose i.e. the electricity tariff for cooking can be considered at Rs 2.55 per unit.

The economic cost of electricity for domestic cooking may be higher than the tariff mentioned above, particularly if large-scale electric cooking will be practised in INPS. It is because the household electric cooking loads coincide with the daily peak loads during morning and evening hours and thereby aggravate the electricity supply situation. The large scale household electric cooking would, therefore, necessitate the installation of large electric generation capacity for meeting the additional peak cooking loads whereas the average demand may remain the same. Thus the large-scale electric cooking at household level may reduce the overall system load factor and thereby lead to diseconomies or high cost of energy. But since there is no concrete basis to estimate the economic cost of electricity in domestic cooking, we shall assume here that the existing tariff reflects the economic cost.

Finally, the economic costs of kerosene and LPG were calculated earlier in Table - 17 which are U.S$6.76/GJ and US$8.59/GJ respectively. The production cost of GH_2 is considered at U.S$11.51 per GJ with the same assumptions as in transport sector. Only gaseous hydrogen is considered for cooking operation. The economic costs of cooking fuels are presented in Table 18.

2.4.2 Environmental Costs

Firewood has a very high environmental cost at this stage in Nepal. The consumption of firewood is one of the main contributing factor to deforestation which has triggered large-scale ecological degradation with tragic consequences on the Himalayan environment and at the same time it has adversely affected the agricultural production as well as the rural health. The deforestation is today manifested in widespread soil erosion, siltation and flooding, and in extreme cases even in desertification. The process of deforestation and soil erosion is particularly active in fragile mountain ecosystem. Second, the scarcity of firewood has lately diverted animal dung and agricultural wastes from field manure to household cooking fuel with detrimental impact on cultivated soils which has further accelerated the process of soil erosion. The diversion of field manure has also caused progressive depletion of nutrients in the soils after each cropping cycle and thus resulted in general decline of agricultural productivity in the country. Finally, the consumption of firewood (including animal dung and agricultural wastes) for domestic cooking has also contributed widespread respiratory disease, particularly among the women in rural areas.

The environmental damage caused by firewood cooking deforestation has created an extremely grave situation in Nepal. No attempt has so far been made to put a price tag on it. But the environmental damage caused by deforestation in Nepal is expected to be higher than the estimated environmental cost fossil fuel earlier (U.S$10.62/GJ) due to its severe impact throughout this region. Hence the environmental damage cost of fossil fuel can be taken as a conservative proxy in this case. In reality, firewood can no longer be advocated as a fuel in Nepal since the deforestation has threatened the very integrity of environment and survival not only within this country but also in the entire Indo-Gangetic belt where hundreds of million people reside.

Hydroelectricity has little environmental cost since the existing system is almost entirely (except one high dam for regulation) comprised of run-of-river type of projects. Hence, for the sake of simplicity, the environmental cost of hydroelectricity is omitted. Both kerosene and LPG will have the same environmental cost and pollution factors of fossil fuels as discussed earlier in transport sector. Finally, hydrogen as a clean, renewable energy has no environment cost. The estimated environmental costs are given in Table 19.

TABLE 19

Environmental Costs of Cooking Fuels

FUEL	Environmental Cost (US $/GJ)	Pollution Factor	Total Environmental Cost (US $/GJ)
1. Firewood	10.62 (min)	85.50	11.21
2. Hydro Elecctricity	......	......	......
3. Kerosene	10.62	76.50	10.03
4. LPG	10.62	48.40	6.35
5. Hydrogen (GH_2)	-	-	-

Note : Pollution factors are assumed as follows :
for firewood as coal, for kerosene as petrol and for LPG as natural gas with mean value for fossil fuel as 81.0 (Viz Table-10)

2.4.3 Relative Efficiencies of Utilization

The relative efficiencies of cooking fuels utilization in Nepal differ according to fuel types as well as the cooking appliances used. In fact, most of the conventional fuels are used with more than one type of appliances. For example, the efficiency of traditional firewood stove is only around 10 percent whereas the improved cooking stoves (ICS) have an efficiency up to 23 percent (14). Similarly, electric cooking in practised and cheap ceramic stoves which are locally made and also imported hot plates. Again, the kerosene stoves can be classified into wick stoves (40 percent efficiency) and pressure stoves (50 percent efficiency). Finally the LPG cooking stoves have also different efficiencies ranging from 50 to 70 percent. The typical efficiencies of the cooking appliances by types of fuels are shown in Table 20.

TABLE 20

Societal Costs of Different Cooking Fuels

Application	Fuel	Appliance	Cost (US $ GJ) Economic	Environmental	Utilization[1] Efficiency (%)	Societal Cost (US$/GJ)	Retail Cost (US$/GJ)
	Fire Wood	Trad Stove	4.48 (Min)	11.21	10	156.90	4.48
		ICS			23	68.22	
Flame Combustion	Hydro Electricity	Ceramic Stove (Min)	16.55	--	45	36.78	16.55
		Hot Plate			70	23.64	
	Kerosene	Wick Stove	6.76	10.03	40	41.98	6.12
		Pressure			50	33.58	
	LPG	Gas Cooker I	8.59	6.35	50	29.88	8.69
		Gas Cooker II			70	21.34	
	GH_2	Gas Cooker	11.51 (Max)	--	80	14.39	
Catalytic Combustion	GH_2	Catalytic Cooker	11.51 (Max)	--	1000	11.51	

Note : 1_/ Only average values are considered

Fire wood	:	Traditional Source (2); ICS (19)
Hydroelectricity	:	Ceramic stove and hot plate (20)
Kerosene	:	Incla stove and pressure stove (20, 21)
GH_2	:	Gas cooker and catalytic cooker (7)

2.4.4 Societal Costs of Cooking Fuels

As stated earlier, each fuel is used for cooking in different types of appliances having different end-use efficiencies. Hence the societal or effective cost per GJ of each cooking fuel is calculated with due respect to the end-use efficiencies of different appliances which utilises this fuel in Table 20. From the societal viewpoint, GH_2 with catalytic combustion is the cheapest option followed by GH_2 with flame combustion. Firewood is the costliest alternative followed by imported kerosene electricity and LPG. But in terms of commercial prices, firewood is the cheapest alternative followed by kerosene, LPG and electricity. Under the existing price structure, the substitution of cooking fuels with hydrogen appears rather difficult despite the high societal costs of firewood and fossil fuels. Hydrogen is likely to compete with imported kerosene and LPG only if one or both of the following conditions will be fulfilled: a) imposition of heavier taxation on imported fossil fuels; and b) valuation of surplus energy and extremely low price for hydrogen production.

The supply factor, however, cannot be dismissed altogether since the Nepalese urban households today usually combine two or even more cooking fuels and maintain different cooking appliance in their households for this purpose due to the periodic shortage of one or another fuel in the market. If the regular supply of hydrogen can be assured, it might be preferred over other conventional, commercial fuels despite its slightly higher cost than that of other fuels.

TABLE 21

Demand Projection for Hydrogen in Houshold Cooking

$$Y_t = E\,H_o(1 + r)^t$$

H_0 = 3,345,052 (1991)
r = 2.61 percent per annum (1981 1991)

Year	Hydrogen Demant (MT) Flame Combustion	Catalytic Combustion
1991 (Base Year)	230809	183978
1992	236833	188780
1993	243014	193707
1994	249357	198763
1995	255865	203950
1996	262543	209273
1997	269395	214735
1998	276427	220340
1999	283641	226091
2000	291044	231992
2001	298641	238047

Note : Total number of households, in base year and annual rate of growth is taken from 1991 Population Census of Nepal (22)

2.5 Potential Demand for Hydrogen in Domestic Sector

The potential demand for hydrogen as a domestic cooking fuel will be investigated in this section. Theoretically speaking, the entire cooking energy requirement of the nation can be supplied in the form of hydrogen. Although the potential demand analysis has limited practical significance at the existing cost price structure, it could nonetheless provide an insight into the upper limit for hydrogen as a cooking fuel in Nepal. Hence a crude exercise in this respect is presented below.

The potential demand for hydrogen as a cooking fuel is based here on a demographic model as shown below:

$$Y_t = EH_o (1 + r)^t$$

where:

Y_t - Total hydrogen demand for cooking in year (base year t = O)
E - Household energy consumption coefficient
H_o - Total number of households in base year
r - Annual rate of growth of households

The total number of households in the base year and the annual rate of growth of households are available from the 1991 census. Hence it is necessary only to estimate the household energy consumption coefficient for the purpose of this exercise.

The household energy consumption coefficient can be estimated in a number of ways. Perhaps the best approach is to derive this coefficient on the basis of LPG consumption. There are a number of similarities between hydrogen and LPG, the only gaseous fuel presently used for cooking in Nepal. Both of these fuels are in gaseous form and use similar appliances for cooking purpose. Further, the same economic group of population, i.e. the relatively affluent high to medium income level families in urban areas are expected to use these fuels. In fact, LPG may be the first commercial cooking fuel that is likely to be substituted with hydrogen in Nepal. It should be noted in the context that despite the relatively high cost and supply problem, LPG has been extremelv popular due to its convenience since the power output from the stove can be quickly varied as required by the cooking operations (e.g., boiling, simmering, etc). In addition, the efficiency of LPG is relatively high due completeness of combustion process. Hydrogen has all the advantages, too.

It has been observed that an urban family consisting of 5 to 6 household members requires, on the average one cylinder of LPG having net weight 14.2 kg per month or approximately 175 kg LPG per annum. In terms of energy context, 175 kg LPG is equivalent to about 69 kg of hydrogen[1]. The household hydrogen requirement norm or coefficient will be derived using two different scenarios: a) flame combustion with highest 80 percent achievable efficiency both in case of LPG and hydrogen; and b) catalytic combustion for hydrogen (GH_2) with 100 percent efficiency. The household hydrogen requirement coefficient in the former case will be 69 kg. household/annum and 55 kg/household/annum in the later case.

The demand projections for the period 2001 are presented in Table 21. It is apparent that the total cooking fuel requirement in Nepal in the form of hydrogen will be only 298,600 Mt for flame combustion and 238,000Mt for catalytic combustion at the turn of the 21st century. Thus, the high energy content as well as high end-use efficiency of hydrogen can substitute the millions of tonnes of biofuels at present consumed in domestic cooking with as little as 240 to 300 thousand tonnes of hydrogen.

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1 Hydrogen has 2.54 times more energy content on weight basis than LPG since its lower heating value is 12.510^4 KJ/Kg as against 49.2 GJ/Mt or 4.92×10^4 KJ/Kg for LPG.

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EXPERT GROUP MEETING ON HYDROGEN ENERGY TECHNOLOGY

6 - 10 July 1992, Kathmandu, Nepal

LIST OF PARTICIPANTS

China

Mr. Liu Hongyun, Deputy Director General, Hydro and Power Department, 62, Shaoshan Road, Changsha, Hunan Province, China 410 007 (Tel : 731-31195, Tlx : 982055 HWPED CN, Fax : 86-731-552834)

Indonesia

Mrs. Nenny Sri Utami, Directorate General of Electricity and New Energy Jl. H.R. Rasuna Said Block X 2, Jakarta 12950, Indonesia (Tel : 516066, 516073, Telex : 62319 energi ia)

Malaysia

Prof. Madya Dr. Abdul Halim Shamsuddin, Head of Department, Department of Mechanical Engineering, Universiti Kebangsaan Malaysia, 43000 Bangi, Malaysia, (Tel 03-8250001, Extn: 2436,3917, Fax : 03-8256086, Tlx : unikeb ma 31496)

Nepal

Mr. Gyani R. Shakya, Senior Engineer, Royal Nepal Academy of Science and Technology, New Baneswor, GPO Box 3323, Kathmandu, Nepal (Tel : 212587, 215316, Fax : 977-1-228690, Tlx : 2599 ronast NP)

Pakistan

Mr. S.N. Sarwar, Manager, Hydrocarbon Development Institute of Pakistan (Karachi Operations), 48-J, Block-6, P.E.C.H.S. Karachi 75400 (Tel : 439476, Fax : 445946)

Philippines

Ms. Marites I Cabrera, Supervising Science Research Specialist, Non-Conventional Resources Division (NCRD), Office of Energy Affairs, Merritt Road, Fort Bonifacio, Makati, Metro Manila, Philippines

India

Prof. O.N. Srivastava, Area Co-ordinator on Hydrogen Energy Programme, Department of Physics, Banaras Hindu University, Varanasi 221 005 (Tel : 54291, Extn : 371, Tlx : 545 304 BHU IN, Fax : 0091-542-312059)

Dr. L.M. Das, Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 110 016
(Tel : 666979/5005, Tlx : 31073087 IIT IN, Cab : TECHNOLOGY, DELHI)

Experts

Mr. T. Nejat Veziroglu, Director, Clean Energy Research Institute, University of Miami, Coral Cables, Florida 33124, USA (Tel : 305-2844666, Fax : 305-2844792)

Mr. Olof Tegstrom, Consultant, Tebetron, Johannesburg. 4, S-871, 31 Harnosand, Sweden (Tel : 46-61115843, Telex : 61115900, ATTN : TEBE)

Mr. D. Richard Neill, Hawaii Pacific Technology and Trade (HP-TAT) Corporation, 98-859, Olena St., Aiea, Hawaii 96701, USA (Tel/Fax : 808-488-8796)

Mr. Gustov R. Grob, CMDC, President, Kellerweg 38, CH 8055, Zurich, Switzerland (Tel :41-1-4630226, Fax : 41-1-4630252)

Mr. Oddvar Holmer, General Manager, Norsk Hydro Notodden, P.B. 40, 3671 Notodden, Norway
(Tel : 473617100, Fax : 473612004, Tlx : 21124 Hydro n)

Mr. Harry Tobienssen, Export Manager, Hydrogen Plants, Norsk Hydro Notodden, P.B. 40, 3671 Notodden, Norway (Tel : 473617100, Fax : 473612004, Tlx : 21124 Hydro n)

Mr. Masaharu Osawa, Economist, Electric Power Development Co. Ltd., 15-1, Ginza, 6-Chome, Cho-ku, Tokyo 104, Japan (Tel : 81-3-3546-2211, Fax : 81-3-3546-9531)

Mr. Kohichi Kobayashi, Engineer, Electric Power Development Co. Ltd., 15-1, Ginza, 6-Chome, Choo-ku, Tokyo 104, Japan (Tel : 81-3-3546-2211, Fax : 81-3-3546-9531)

Consultants

Mr. Khilendra Narsingh Rana, Institute for Sustainable Development, P.O. Box 4006, Krishna Galli Pulchowk, Lalitput, Kathmandu, Nepal (Tel : 523-657/522-531, Fax : 977-1-526467, Tlx : 2476 ISD NP)

United Nations Organizations

ESCAP

Mr. Charles Mulagwe, Associate Expert, Division of Industry, Human Settlements and Environment, The United Nations Building, Rajadamnern Avenue, Bangkok 10200 (Tel : 2829161-170, Tlx : 82392, 82315 ESCAP TH, Fax : 2829602)

Mr. S.R. Din, Economic Affairs Officer, Division of Industry, Human Settlements and Environment, The United Nations Building, Rajadamnern Avenue, Bangkok 10200 (Tel : 2829161-170, Tlx : 82392, 82315 ESCAP TH, Fax : 2829602)

UNIDO

Mr. George Tabah, Industrial Development Officer, Industrial Technology Development Division, UNIDO, P.O. Box 300, Vienna International Centre, A-1400, Vienna, Austria (Tel : 43-1-21131, Fax : 43-1-232156, Tel : 135612 UNO A)

APCTT

Mr. Ove Chr. Bugge, Director, Asian and Pacific Centre for Transfer of Technology, 49 Palace Road, Bangalore 560 052, India

Ms. Jaana Pelkonen, Associate Expert, Asian and Pacific Centre for Transfer of Technology, 49 Palace Road, Bangalore 560 052, India

RONAST

Mr. Parashar N. Suwal, RONAST, New Baneswor, GPO Box 3323, Kathmandu, Nepal (Tel : 212587, 215316, Fax : 977-1-228690, Tlx : 2599 ronast np)

Dr. Ramesh Man Singh, RONAST, New Baneswor, GPO Box 3323, Kathmandu, Nepal (Tel : 212587, 215316, Fax : 977-1-228690, Tlx : 2599 ronast np)

Dr. T.M. Pradhananga, RONAST, New Baneswor, GPO Box 3323, Kathmandu, Nepal (Tel : 212587, 215316, Fax : 977-1-228690, Tlx : 2599 ronast np)

OBSERVERS

Mr. Ganesh Ram Shrestha, Executive Director, The Centre for Rural Technology, Tripureswor, P.O. Box 3628, Kathmamdu, Nepal (Tel : 213885, Fax : 977-1-228106)

Mr. Upendra Dev Bhatta, Nepal Electricity Authority, Engineering Directorate, Design Department, Ratna Park, Kathmandu, Nepal (Tel : 225499)

Mr. Lila Nath Bhattarai, Energy Engineer, Water and Energy Commission Secretariat, Singh Durbar, Kathmandu, Nepal (Tel : 227699, 228968, Fax : 227185)

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